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FIG. 1. Robot camera, basic 35-mm film format unit for the multiband-multiemulsion quadricamera, fitted with 150-mm screw mounted telephoto lens for detailed water pollution studies. Robot Star 50 (illustrated), housing on top of camera contains stainless steel spring motor which drives automatic film advance for 50 exposures without rewinding.

35-mm Quadricamera

Inexpensive multiband and multiemulsion system is advantageous for coastal and wetland studies.

INTRODUCTION

MULTISPECTRAL aerial photographic systems are proving to be more and more valuable to earth scientists, ecologists, and engineers in the interpretation and monitoring of the natural environment. A recent article in this journal (Slater, 1972) discussed the past and future requirements and tolerances for multiband aerial camera systems in relation to their geometric and spectroradiometric properties. However, aerial multispectral photographic systems, of a less demanding metric nature, are rapidly being found to be useful by scientists and engineers in flying reconaissance and non-photogrammetric multispectral studies. For example, development of analytical techniques for the aerial study of coastal and wetland regions using multispectral photographic systems have interested both authors in recent years.

ABSTRACT: *A quadricamera system for aerial non-metric photography was designed around the Robot 35-mm camera system. The quadricamera allows both multiband and multiemulsion techniques and was designed for multispectral inventory, reconaissance and non-photogrammetric studies of shorelines, marshlands, estuaries and harbors. Standard photographic equipment allows for inexpensive construction, and the 35-mm film format allows for inexpensive operation. Compact design allows for use from light aircraft, also reducing operation costs. The Robot quadricamera system is completely mechanical in operation and requires no electric power supply. Internal spring-drive motors within the camera provides for shutter cocking and film advance, and 50 exposures are possible before rewinding. A special mechanical shutter-release system, designed for the quadricamera, allows simultaneous tripping of all four cameras.*

Multispectral aerial studies, for this and other types of terrain, are often conducted using standard 9 × 9-inch photogrammetric aerial cameras and flying several repetative flight lines for each spectral region or emulsion. However, a variety of other aerial systems governed by various factors, from availability of standard equipment to economy of operation, have been also used. In addition, progressive development in the design of these systems has taken place over the last several years to influence the senior author in the design of the present inexpensive multispectral-multiemulsion quadricamera system. In a similar manner, the more recently engineered sophisticated multiband camera, the S109 for Skylab, has basic features developed for earlier systems, notably the S065 in the Apollo 9 multispectral studies.

Development of Multiband Camera System

The earliest multiband studies, actually multiemulsion, were usually simply the use of both black-and-white and color film, such as Olson's study (1964) using standard 9 × 9-inch photogrammetric aerial cameras in the mapping of marsh vegetation in Merrymeeting Bay, Maine. Later studies included color-infrared emulsions, such as Stroud and Cooper's study (1967) to determine the net primary productivity of a North Carolina salt marsh. Again a standard aerial photogrammetric camera (Wild RC 8) was used and repetitive flight lines were flown to expose both Ektachrome Aero Color and Ektachrome Infrared Aero films. The flying elevation was only 3,000 feet to produce the desired image scale of 500 feet per inch. The development and use of special multilens cameras using 70-mm film during this time period simplified multispectal or multiband aerial reconaissance studies for land resource inventory (Lent and Thorley, 1969) as well as tidal-marsh channel mapping (Pestrong, 1969). Single standard 35-mm cameras were also used to test various emulsions (black-and-white, color, and color-infrared) for aerial photographic reconaissance detection of potato disease. (Cooper and Manzer, 1967).

In response to this growing demand for multispectral aerial photographic surveys, various camera systems of differing multispectral nature have been developed. First, the terms *multispectral* and *multiband* have often been used interchangeably, especially in referring to aerial camera systems, although the term could be applied to other types of sensing instruments. However, the term *multisensor* has been used for simultaneous observations, sometimes with more than one instrument, over a wide range of the electro-magnetic spectrum and may or may not include the visible portion sensed by the aerial camera systems. Finally, *multiband spectral* has been used as a general term for all the previously mentioned techniques (Lent and Thorley, 1969). The present senior author does not want to compound this terminology further except to point out that some multispectral camera systems can image several portions of the spectrum on only one type of an emulsion at a time, whereas others can image on different types of emulsion durinv the same photographic sequence.

Increased interest in color and color-infrared emulsions required that certain multispectral camera systems also be multiemulsion—handling several different emulsions simultaneously. For example, the Itek 9-lens multiband camera, among the earliest highly engineered multispectral cameras, allowed simultaneous photography in several portions of the spectrum on three separate rolls of 70-mm film. Three of each of the nine photos were imaged on the same roll of film, thus the camera had partial multiemulsion ability, but was not often used in this manner. In most applications, it was loaded with two rolls of panchromatic black-and-white film and one roll of infrared black-and-white film with various filters on all nine lens to produce a multispectral analysis (Molineux, 1965). A later four-lens multispectral Fairchild camera imaged on a *unitary* 9-inch wide roll of film or four separate rolls according to Yost and Wenderoth (1968). The recent, commercially available, Mark I multispectral camera of International Imaging also uses 9-inch aerial film with a 4-lens system and is therefore not basically multiemulsion as described above. Itek's newest is the *multispectral photographic facility* (MPF), developed for earth resources surveys (S109)in NASA's Skylab program. Taking six simultaneous photos, each lens, matched in focal length to the appropriate spectral band, has its own film magazine, drive and controls for 2¼ by 2¼-inch format.

Special and costly engineering to produce the above multilens-multispectral camera systems early led to the use of modified, but standard, *off the shelf* non-aerial camera systems. The best known of these systems usually combined four 70-mm Hasselblad cameras to operate simultaneously. Marlar and Rinker (1967) developed such a Hasselblad four-camera system for the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL) to be used in either automatic or manual operation. A similar unit was designed for experiment S065 (Multiband Terrain Photography, hand held) of NASA's Apollo 9 flight but which was mounted in an observation port for the photographic mission. Another similar Hasselblad system was designed for conventional aerial photogrammetric camera mounts and the term *quadricamera* was coined (Ulliman, Latham, and Meyer, 1970).

Robot Camera System

With multispectral and multiemulsion aerial photographic systems and techniques developing as indicated, the thrust of investigations by earth scientists and engineers was turning to the acquisition of *ground truth*—obtained, when possible, concurrently with the aerial surveys. To this end, the senior author became interested in developing criteria for the recognition of estuarine water pollution using the new multiemulsion and multispectral techniques and relating it to field confirmation (Fisher, 1969). As the use of the Hasselblad system as previously described was not economically possible, the study was originally planned around an existing Graflex camera system with the ability to accept various size interchangeable film backs. Plans were to use a 70-mm back for testing of Infrared Ektachrome color, positive emulsion, the same size film as in the Hasselblad system. However, only one Graflex camera was available and repetative flights testing different emulsions were planned. Just before the project started, the infrared-color emulsion was made available in the 35-mm format and funds were also available to acquire an electric drive motorized film advance 35-mm system (Beseler Topcon was considered). A motorized drive would allow sequential frames to be exposed rather than just the single frame of the Graflex. Sequential coverage is especially necessary for coastal studies.

Non-motorized twin hand-held Leica M-3 cameras had been used that same year to test the feasibility of the small camera format with color and color-infrared film to detect and monitor stream pollution (Cooper, *et al.*, 1969). The two cameras were tandem mounted on a bar, with a double cable-release assembly to trip the two shutters simultaneously, although in rough-weather flying conditions the shutters were tripped by hand. More recently Rinehardt and Scherz, (1972) utilized two motor driven 35-mm Nikon cameras for a multiband NASA study and recommended the microfilm system for storage, indexing and viewing of the 35-mm film. The senior author of the present article utilizes a microfiche system for detailed viewing of 35-mm film. It was during the investigating of motorized 35-mm cameras in 1969 that the senior author became aware of the Robot 35-mm automatic camera system. For the price of a single electric motorized reflex 35-mm camera with remote shutter release and expanded film back (a cost around $1,600), four Robot cameras could be assembled into an aerial quadricamera without any loss of necessary engineering features.

The basic Robot camera system has several features that make it particularly useful for small camera aerial photographic use (Figure 1). First, although an off-the-shelf item, the camera is well-made, dependable, and has been around in its basic format for over three decades in special scentific and engineering applications. It was used to produce some of the earliest deep-sea photographs (Ewing, et. al., 1946) and more recently photographic surveillance in banks. In addition, banks of these cameras were used on motion picture sound stages to photograph automatically scene placements for record. In comparison, other 35-mm cameras with automatic advance systems similar to the 70-mm Hasselblad were usually electrically motorized with an electric relay for remote shutter release, as well as being single lens reflex with built-in light meters—excellent features, but not all that necessary for an aerial photographic system and especially not for a quadricamera system where duplication of features raises the cost of the system.

The Robot system is basically mechanical in operation, in contrast to other 35-mm systems which are primarily electrical. It has a built-in stainless-steel spring motor which gives up to 50 exposures per winding (single motor gives 18 exposures). Pressing the shutter release for an exposure, automatically takes the picture, counts the exposure, transports the film and cocks the shutter for the next picture. A rotary shutter allows speeds to 1/500 of a second and Schneider screw mount lens from 30 mm to 150 mm are available.

Framing is by a standard built-in viewfinder, seldom used in aerial photography, and thus one does not pay for an unused rangefinder, electric eye or reflex system. The format incidently is 24×24-mm square, rather than the usual 35-mm rectangular format, and thus is similar to the more common aerial photography square format. The problem of vertical *vs.* horizontal framing is eliminated in using this square format. Two other features of interest for aerial photography are, a safety lock which prevents accidental exposures and a cartridge-to-cartridge film loading system. This latter feature helps reduce friction and scratching as well as permitting rapid removal of completely or partly exposed film and fast reloading. Last but not least, the Robot Star model camera is compact, being only 4¼ × 3 × 1¼ inches in size exclusive of the lens.

The initial choice of this camera system for constructing the quadricamera has been reinforced by a recent article in *Photogrammetric Engineering* (Karara, 1972) that ranks Robot, with Hasselblad, Linhof Technika, etc., as one of the better *non-metric* cameras, non-metric applying to those cameras that can be used for aerial reconaissance but not photogrammetric mensuration. Increasing use of inexpensive aerial systems of this type for terrain environmental studies by scientists and engineers has indicated (Karara, 1972) that with the appropriate reduction techniques, these better non-metric cameras can achieve the same order of accuracy as the close-range photogrammetric cameras.

The first model of the Robot quadricamera was completed in 1969, used in the proposed estuarine water pollution study (Fisher, 1970) and again later for a study of coastal geologic processes (Fisher, 1971a). A modified system was reported in the press (Fisher, 1971b) with four Robot Star 25 cameras, mounted on a common base, similar to the CERRL Hasselblad mounting. Lenses were Schneider-Kreuznack Tele-Xenar 150-mm telephoto lens, the same make lens as used on the earlier Itek 9-lens multiband camera. Telephoto lenses were chosen for the first study for detailed spot pollution analysis, but a normal lens is recommended for most studies. Mounted with the cameras was a Norwood Sekonic-Photogrid light meter which, as used by the U.S. Coast and Geodetic Survey in aerial surveys, separated the light sensor (with a 25° field of view) from the galvaonmeter (Harris, 1968). For the quadricamera system the meter was mounted facing the operator and the cell facing the aerial scene being photographed.

Detailed framing was done with an auxillary Lumineux 150 viewfinder mounted in the center of the four camera cluster. The four camera shutters were operated by two double-cable releases in each handle. It was found in practice that the operator could trip both double cables simultaneously. At this time on the West Coast, Pestrong (1971), in a study evaluating the impact of geologic hazards using multiband photographs, designed a four-camera plexiglas frame similar to the earlier 1970 Robot quadricamera which also used two double-cable shutter releases. Pestrong's system was also designed for 35-mm cameras, although the particular cameras used were not mentioned. Interest in a four-camera system was undoubtedly the result of Pestrong's earlier study which used a variety of multiband imagery, including nine-lens

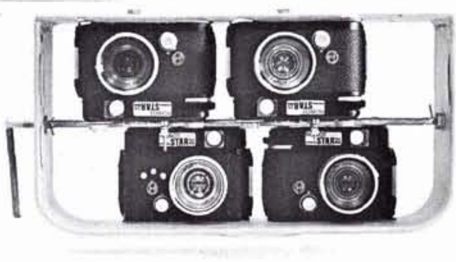

FIG. 2. Robot quadricamera system containing four automatic Robot Star 25 cameras fitted with four 31.5-mm wide-angle lenses for wetland and coastal inventory studies. After each exposure, the mechanical drive system cocks the shutter, transports the film and counts the exposure. Tandem reverse mounting of cameras necessary for operation of simultaneous shutter release operated by handle to left of box frame.

multiband imagery in a study of tidal marshes (Pestrong, 1969). The results suggested to Pestrong "that nine-lens multiband imagery is excessive and that for similar use, could be reduced to four-lens imagery," an imagery system popular in early Hasselblad 70-mm design, by Fisher in 35-mm format, as designed with a similar design by Pestrong.

Since 1970 the original Robot quadricamera mounting has been slightly redesigned for the junior author's salt marsh study and in that form it is presented here (Figure 2). Of the four Robot cameras, two are still mounted upside down in a box frame but are slightly forward of the second two in order to utilize a mechanical system (designed by the junior author) for tripping the four shutters simultaneously (Figure 3). Movement of the com-

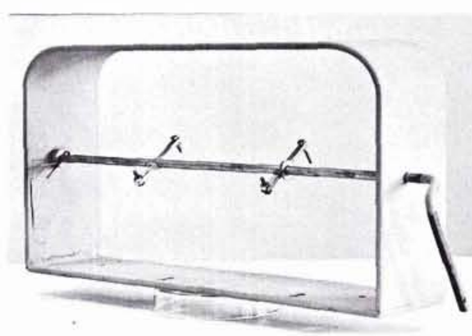

FIG. 3. Design of shutter release system which allows tripping of four shutter simultaneously. In operation, the shutter release handle on the right (operator's view) is rotated clockwise about 10°, turning the center axle rod which rotates the two cross bars. Adjustable bolts are included to make contact, tripping the four camera shutter release buttons simultaneously. A quick-release wrist safety strap is fastened to the hole in the lower part of the shutter-release handle.

FIG. 4. Operating position of quadricamera for vertical photos from window of light high-wing aircraft. Compact nature of quadricamera allows hand-held use from plane window. The window fastening was modified to allow the window to be opened fully while in flight.

mon shutter handle outside the box frame rotates an axle with two cross-bars having ordinary bolts which allow for adjusting travel distance and which make contact with the shutter buttons on each camera. This system is more compact and more reliable than the double-cable shutter system used on the earlier quadricameras as well as on other multicamera systems. All four camera backs can still be opened and reloaded without removing the cameras from the frame. A quick-release wrist strip is fastened to the unit to prevent loss in use.

In aerial use, the entire unit, because of its compact nature, is easily hand-held out the window of the plane for vertical shots (Figure 4) whereas for oblique shots, the unit can be aimed from inside the plane. A hand-held external mount for actuating the quadricamera from inside a helicopter was built after the design of Avery (1968, p. 140) but it was found that, in practice, a hovering helicopter set up vibrations that produced unsharp photographs. This disadvantage, together with the added costs, resulted in not using helicopters for the various aerial studies.

In practice, the quadricamera was used from a small high-wing airplane (Cessna 150 or 172) with a window on the left (normally pilot) side that opens upward and can be altered before take-off so that it can be fully opened during flight, as shown in Figure 4. The pilot flies the plane from the right side (co-pilot side). All flights are conducted on bright, clear, cloudless days with as little wind as possible. Wind and related turbulence makes good low-altitude close-up aerial photography difficult. In coastal areas, wind activity usually picks up by mid-afternoon, so aerial photography flights are best in late morning. Because easily accessible light planes are used, final flight arrangements can usually be made the morning of an acceptable flight day if prior notice is given the charter plane.

In general, a third person accompanied the flight. Seated in the rear, he directed the pilot as to the flight line and signaled the photographer at the required time interval (measured in seconds) necessary to produce the necessary photo overlap. This time interval is calculated beforehand, taking into account the photo scale desired, the required flight altitude and the focal length of the lens system used. Flights over most unpopulated coastlines and wetlands can be below 1,000 feet and a normal focal length lens can be used. Estuaries and harbors are often more populated and flying altitude has to be over 1,000 or 2,000 feet, with a need for longer focal length, telephoto, lens. Positioning for vertical shots was done by having the pilot reduce speed and then slipping the aircraft sideways along the flight line.

ADVANTAGES OF QUADRICAMERA DESIGN

★ Small camera format (35 mm) allows lower-cost aerial photography for reconnaissance, inventory, detection and monitoring. It also allows determination of best photographic conditions for larger format photographic mapping.

★ Quadricamera system allows use of different 35-mm film emulsions (multiemulsion) during a single flight, reducing air time and producing simultaneous four-frame coverage.

★ Quadricamera system also allows use of a single emulsion (often black-and-white panchromatic) with different filters for multispectral aerial photographic studies.

★ Hand-held compact cameras and mounting allows use of light aircraft with reduction in time and monies. Light aircraft also allows easier accessibility for prime flying photographic conditions and coordination with ground-data collection parties.

★ The quadricamera system is designed around off-the-shelf photographic equipment and is completely mechanical in film advance, shutter cocking and shutter release. No electrical power supply is required. Due in part to these factors, the initial cost of the system is relatively inexpensive.

★ Flight strip sequences of 50 exposures per cassette loading can be made, with up to 5 exposures per second using the mechanical film advance system of the Robot quadricameras. Lenses of various focal lengths are available and are easily changed in the body mounts.

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References

Avery, T. E., 1968, *Interpretation of aerial photographs*, 2nd ed. Burgess Publishing Co., Minneapolis, 324 pp.

Cooper, G. R. and Manzer, F. E., 1967, *Aerial photographic methods of potato disease detection*. Maine Agr. Exp. Sta., Bull. 646, 14 pp.

Cooper, R. A., McGuinness, R., Mintzer, O. W., Ricca, V. T., Shumate, K. F., and Willson, R. D., 1969, Application of color aerial photography in water pollution studies. *New Horizons in Color Aerial Photography*, Amer. Soc. Photogrammetry and Soc. Photo. Sci. and Eng., (Seminar Proc.), p. 99-106.

Ewing, M., Vine, A., and Worzel, J. L., 1946, "Photography of the ocean bottom." *Jour. Optical Soc. of Amer.*, V. 36, n. 6.

Fisher, J. J., 1969, "Criteria for recognition of estuarine water pollution by aerial remote sensing (abs.)." *Water Resources Res. Catalog*, U.S. Dept. Interior, V. 5, p. 527.

———, 1970, "Criteria for recognition of estuarine water pollution by aerial remote sensing." *Final report, U.R.I. Water Resources Center*, 13 pp.

———, 1971a, "A Multispectral aerial photographic system for coastal geologic processes." (abs.), *Geol. Soc. Amer. Abs.*, V. 3, No. 1, p. 28.

———, 1971b, "Simple multicamera system for water pollution." *Jour. of Remote Sensing*, V. 2, p. 10.

Harris, W. D., 1968, "Aerial photographic exposure." Sub-chapter 2.3, in *Manual of Color Aerial Photography*, Editor J. T. Smith, Pub. Amer. Soc. Photogrammetry, 550 pp.

Karara, H. M., 1972, "Simple cameras for close-range application." *Photogrammetric Engineering*, V. 38, p. 447-451.

Lent, J. D. and Thorley, G. A., 1969, "Some observations on the use of multiband spectral reconnaissance for the inventory of wildland resources." *Remote Sensing of Environment*, V. 1, p. 31-45.

Marlar, T. K. and Rinker, J. N., 1967, "A small four-camera system for multi-emulsion studies." *Photogrammetric Engineering*, V. 33, p. 1252-1257.

Molineux, C. E., 1965, "Multiband spectral system for reconaissance." *Photogrammetric Engineering*, V. 31, p. 131-143.

Olson, D. P., 1964, *The use of aerial photographs in studies of marsh vegetation*. Maine Agr. Exp. Sta., Bull. 13, 62 pp.

Pestrong, R., 1969, "Multiband photos for a tidal marsh." *Photogrammetric Engineering*, V. 35, p. 453-470.

———, 1971, "Evaluating geologic hazards with multiband photography." *Jour. of Remote Sensing*, V, 2, No. 2, p. 4-9.

Rinehardt, G. L. and Scherz, J. P., 1972, "A 35-mm aerial photographic system" (abs.). *Photogrammetric Engineering*, V. 38, p. 597-598.

Slater, P. N., 1972, "Multiband cameras." *Photogrammetric Engineering*, V. 38, p. 543-555.

Stroud, L. M. and Cooper, A. W., 1967, *Color-infrared aerial photographic interpretation and net primary productivity of a regularly-flooded North Carolina salt marsh*. Water Resources Research Institute of the Univ. of N.C., Proj. No. A-003-NC, 86 pp.

Ulliman J., Latham, R., and Meyer, M., 1970, "70-mm quadricamera." *Photogrammetric Engineering*, V. 36, p. 49-54.

Yost, E. and Wenderoth, S., 1968, "Additive color aerial photography." App. 1, part 2 in *Manual of Color Aerial Photog.* (also V. 33, 1967, Photog. Eng.)