CONTINUOUS STRIP AERIAL PHOTOGRAPHY

Phillip S. Kistler, Chicago Aerial Survey Co.

ONE of the most effective photographic developments of World War II was the Sonne stereoscopic strip camera. This unique camera made possible a completely new type of aerial reconnaissance by permitting low altitude photography at extremely high plane speeds. The large photo scales produced (up to 1/300) were very helpful in the reconnaissance of puzzling enemy installations. Strip photography was much more effective than standard photography for this purpose.

Operation

The principle of strip camera operation is quite different from that of ordinary aerial cameras. The film is moved continuously past a slit in the focal plane of the camera, synchronized to the movement of the ground image as the airplane passes over the terrain. Thus, as the airplane moves in flight, the film continuously records the terrain passing below on an uninterrupted strip photograph. With this method of photography there is no differential image movement during exposure. For this reason high exposure speeds are not necessary to stop motion. Instead of a shutter, the width of the focal plane slit governs the exposure time. (Exposure = slit width/film speed). Because of the image-film synchronization it would be possible to take a sharp photograph with the Sonne camera at an altitude of 200′ with airplane speeds as high as 1000 mph.

Stereoscopic photographs are obtained by partitioning the lens cone and using two lenses. A small rotation of the lens turret moves one lens forward and the other lens backward with respect to the slit. A plane from the slit through the center of the forward lens would project to the ground ahead of the camera. A similar plane through the after lens would project behind the camera.

Thus the same image is photographed on one-half of the film by the forward lens as the airplane approaches, and on the other half of the film by the second lens after the airplane passes over. This gives the stereoscopic separation necessary. The angle between the two geometric planes is known as the stereo lens angle. This angle controls the stereoscopic parallax values. The lens turret is calibrated for stereo lens angles between 0° and 20°. An angle of about 5° gives approximately normal stereo values for the average observer.

The strip photographs can be viewed stereoscopically on the continuous roll by means of a special mirror type stereoscopic viewer.

An interchangeable single lens cone is available for non-stereoscopic strip photography.

Synchronization: Film synchronization is maintained according to the formula

$$\frac{Vf}{Vp} = \frac{F}{H}$$

or

$$VF = \frac{FVp}{H}.$$

where

Vf = Film speed
Vp = Plane speed
F = Focal length
H = Altitude

From the above it is evident that the film speed must be changed whenever either altitude or plane speed is changed. A circular slide rule computer is available for quick computation of film speed and exposure. When synchronization control is manually maintained the film speed can be pre-set for desired altitude and plane speed; or camera settings can be set in flight by remote control cables. Synchronization can be in error as much as 25% and sharp photos will still be obtained although the image is distorted by being either compressed or elongated in the direction of flight.

A method of automatic synchronization has been developed which maintains synchronization very closely. By means of an intereference pattern set up by two optical grids in a scanning device, an electronic cycle is produced by photo cells. The cycle varies with the plane's ground speed and altitude. In other words the ground detail passing under the plane is used to excite the photo cells which produce a small electric current cycle representing a direct measurement of the plane's angular velocity. This angular velocity is directly related to ground speed and altitude. A magnetic impulse from the focal roller of the camera also produces an electric current cycle. These two cycles are balanced in a small amplifying unit. When the camera cycle falls behind the ground cycle a servo motor is energized which increases the film speed. When the camera cycle gets ahead, the servo motor decreases the film speed. This synchronizing unit maintains synchronization very satisfactorily with changing airspeeds and rapidly changing altitudes (i.e., rough terrain). With automatic synchronization the slit must be varied to maintain constant exposure values as the film speed changes. This is automatically controlled by a mechanical connection between the servo motor film speed control and the slit control.

Development

The Sonne continuous strip camera was developed and built by the Chicago Aerial Survey Company for the U. S. Navy and Army Air Corps. The Navy type camera is equipped with a 100 mm. focal length stereo lens cone and an interchangeable 6″ single lens cone. The Navy stereo lens cones are specially calibrated for precise stereo lens angle to be used for photogrammetric work. The Air Force camera uses an 88 mm. stereo lens cone and the 6″ single lens cone. Both Army and Navy cameras use the automatic as well as the manual film synchronization.

The film capacity (9½″ wide, 200′ long) is enough to photograph a strip of terrain more than 20 miles long at a scale of 1 in. = 50 feet. The complete automatic installation weighs a little under 100 pounds. Special mirror viewers are provided for uninterrupted viewing of the strip photographs. A "floatingmark" comparator has been developed by Chicago Aerial Survey Company for photogrammetric measurements on the strip film.

Wartime Application

The wartime uses of strip photography required very low flying at very high plane speeds. This type of combat flying proved to be relatively safe. With the cameras mounted in fast fighter planes flying at altitudes of 100 to 500 feet the only antiaircraft fire encountered came from hastily manned small arms and light machine guns. Usually the plane had flashed over its target and disappeared before enemy gunners could be alerted. The photos so obtained were remarkably sharp and of extremely large scale. Naturally at such low altitudes, the coverage was very narrow in width. This limited the use of the camera to the coverage of spot targets or carefully selected strips of terrain.

During the war the writer was in the U. S. Navy and worked with the strip camera particularly in the development of water depth measurement and later in the combat application of strip photography in the western Pacific area. For this reason the uses of strip photography in operations involving the Navy are discussed in much more detail than those involving the Army.

The most important use of strip photography by the Navy was in the stereoscopic measurement of water depths on the assault beaches of enemy held coral islands in the western Pacific. The Sonne camera was also used by the Navy to great advantage in ground support photography in co-operation with the Tenth Army and the 3rd Marine Amphibious Corps throughout the Okinawa campaign. This latter application was very effective in the location of Jap cave defenses and the detection of camouflage. In Europe the Army is reported to have had fine results in low level strip reconnaissance, both in vertical and oblique photography.

Although synchronization can not be perfectly maintained for more than one distance from camera to object there is enough leeway in synchronization that sufficiently sharp stereo photos can be obtained from an obliquely mounted Sonne camera. Strange background distortions are apparent but the oblique photos have proved very useful for special reconnaissance purposes.

Photogrammetric measurements:

For measuring vertical height on stereo strip photos the following formula was developed:

$$\frac{h}{\frac{1}{2}P} = \cot a/2$$

$$h = \frac{P}{2} \cot a/2$$

$$\frac{P}{p} = \frac{H}{F}, \qquad P = \frac{pH}{F}$$

$$h = \frac{pH}{2F} \cot a/2$$

$$\text{or} \quad \frac{dh}{dp} = \frac{H}{2F} \cot a/2$$

a = Stereo lens angle
H = Alt. of camera above datum plane
O = Any point on datum plane
A = Any point at distance below datum plane
F = Focal length of camera
p = Difference in parallax between O and A on photo
P = Difference in parallax between O and A on datum plane
$\frac{dh}{dp}$ = Rate of change of height with respect to parallax, or height per unit parallax
h = height

When the above formula is used errors in synchronization and altitude are reflected directly in the results. The flying altitudes are so low that small errors in altitude result in relatively large errors in percentage of altitude. For this reason the synchronization ratio is substituted for altitude and focal length:

$$\frac{H}{F} = \frac{Vp}{Vf}$$

Where Vp = Ground speed
Vf = Film speed.

The most practical formula becomes

$$\frac{dh}{dp} = \frac{Vp}{2Vf} \cot a/2.$$

With the latter formula, errors in altitude and synchronization are automatically eliminated. The only error remaining is the difference between air speed and actual ground speed. This can be minimized by calibration of the photo plane's airspeed installation and carefully correcting for wind velocity and direction in each photographic run. At high military plane speeds this error becomes almost negligible.

Combat application:

The method of depth determination was first used in combat operations by the U. S. Navy for the invasion of Okinawa. For this operation the Sonne cameras were mounted in Grumman F6F(Hellcat) airplanes based aboard the aircraft carrier USS *Hornet.* In a check made by the writer on the coral reef assault areas after the amphibious landings were made, the average depth error was $\frac{3}{4}$ foot and the largest error was under 2 feet. A sea wall was measured with less than 2 inches error.

After the initial landings the Sonne cameras were put in operation at Yontan airfield, Okinawa in Hellcat fighter planes. During this period depth measurements were successfully made for the invasion planning of several small islands in the Ryukyu chain north of Okinawa. Among these were Aguni Shima, Iheya Shima, Kume Shima, Yoron Shima, Izena Shima, Tokuno Shima and Kikai Jima. One flight was made to photograph beach areas in southern Kyushu.

On Okinawa itself the camera was very successfully employed in support of ground operations. An enemy mine field was photographed at a scale of 1/300 (1″ = 25′). The photos clearly showed that the mine pits had been prepared but the Japs had not found time to fill them with mines. On another occasion a Jap command post was located on Sonne photos by tracing a communication wire laid on the ground to a position in a cave mouth carefuly concealed with vegetation. The Sonne camera was also used to good advantage in Hellcat fighter planes based at Iwo Jima for the location of hidden enemy radar stations at Chichi Jima.

Both in Europe and in the Pacific the large scale and extremely sharp photographs produced by the strip camera proved to be of immense value in military operations.

Commercial Application

The advantages of the Sonne camera are (a) large scale, (b) convenient continuous viewing arrangement (either single strip or stereoscopic), (c) very accurate height measurement of buildings, trees, cliffs, walls etc.

One of the strip camera's chief advantages, that of extremely sharp large scale photography, results in a necessary limitation of lateral coverage. For this reason the camera is particularly adapted to the survey of linear features such as highways, power-lines, aquaducts, pipelines, waterways, railroads, strand lines etc. The Sonne camera provides a convenient means of recording and viewing these linear subjects for purposes of planning, maintenance etc.

An application can probably be found in forestry. The large scale would be excellent for the determination of tree types, accurate stem count and accurate measurement of tree heights. Even in fairly dense forest areas Sonne photography often shows the extent and type of brush cover in the area between the trees.

Because of the newness of strip photography several commercial applications might arise which cannot be anticipated. It is felt that most of the commercial applications of the strip camera would supplement rather than replace standard aerial photography.

RESOLVING POWER

AT a local meeting of the American Society of Photogrammetry held in the auditorium of the Commerce Building, Washington, D. C. on May 6, 1946, representatives of the Technical Division 5 of the Engineer Board, Corps of Engineers, presented the following program: Introduction and resume of Engineer Board developments in photogrammetry, Major W. C. Dude; New Engineer Board developments in photomapping equipment, J. T. Pennington; Military photogrammetry in action in Europe, Major J. W. Locke; Captured German mapping equipment (discussion and slides), A. M. Wilson. On Exhibit were major items of captured German equipment. It is hoped that the papers presented at that time will be available to PHOTOGRAMMETRIC ENGINEERING for publication at a later date.