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Photogrammetry Is Looking Up

The Use of Stellar Photographs in an Aerial Photogrammetric Application

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A RESEARCH program currently being pursued at the Mapping and Charting Research Laboratory is outlined in this paper. This work is sponsored by the Flight and All Weather Test Directorate of the Wright Air Development Center, contract number AF 33(616)-3448.

The Air Force has flight instruments and navigational and guidance equipment under continuous development. Many of these systems produce information about the heading and attitude of an aircraft in flight, to a reasonably good order of accuracy; of course, the objective of continuing programs is even more accurate systems.

In the case of navigational and guidance systems of the inertial type, the program includes serious efforts to reduce size and weight in the operational units without affecting the accuracy of the continuous flow of information. It is all very well to say that an item has a certain average or maximum error in operation, and such figures are usually offered by the manufacturer, having been extrapolated from quasi-operational bench testing situations. However, it is obviously very desirable to have test data taken under the actual operating condition, that is, from an aircraft in flight.

There has been required an independent source of attitude and heading information of a higher order of accuracy than that produced by the inertial systems. At least one organization has successfully used daylight photography of ground targets on a carefully controlled range to obtain this information. From this photogrammetric data roll, pitch and heading of the aircraft can be derived from the instant of taking the photograph, but continuous data cannot be obtained. It is possible, however, to take photographs at intervals of a few seconds, so that a fairly complete record of aircraft attitude and heading throughout a maneuver can be compiled. The necessary increase in accuracy over the inertial data is purchased with time: in place of a continuous and essentially instantaneous display of roll, pitch and heading, the photogrammetric system produces these results several days later. This general approach is satisfactory, because post-flight comparison of the photographically recorded readings of the inertial system output and the photogrammetric data can be made for any predetermined in-flight situation.

There is, however, a serious practical difficulty in this scheme. Flight testing situations involving long distances or complicated area coverages produce an almost insurmountable problem of furnishing adequate ground control.

The answer to this difficulty is found when operations are carried out at night, and the cameras take photographs upwards instead of down. Star images are exceedingly well defined, being essentially point images. They are thus easy to locate and measure with accuracy on the negative. In addition, there is practically no confusing extraneous detail. Furthermore, the angular positions of many thousands of stars in an inertial reference system are known to within a small fraction of a second of arc. The stars are ideal control points.

The problem of operating in flight attitudes including large angles of roll or bank are no greater than for level flight, because stars are available for use as control points from horizon to horizon. No basic change in reduction methods is needed to make use of star images regardless of the zenith distance, because the camera negative is always parallel to the tangent plane of the spherical reference surface containing the control points. The problem of operating over large distances does not introduce difficulties since stars are available over the entire sphere of the sky.

In order to produce from stellar photographs the three angles of aircraft orientation (roll, pitch, and heading) the following data are required:

1. The film coordinates of star images whose astronomical coordinates are known.
2. The Universal Time.
3. The latitude and longitude of the aircraft.
4. The camera properties.

Three star images are used in practice to determine the right ascension and declination of the camera axis, and a line through two star images in the film plane is used to establish the amount of rotation of the camera about the camera axis. The latitude and longitude of the aircraft, together with the Universal Time, suffice to provide the Local Sidereal Time, which is used to established the relationship between the spherical coordinate system on the earth's surface and the spherical coordinate system of the celestial sphere. It is a simple step forward to relate the camera axis and rotation to the local vertical. A further computation distributes the tilt and rotation into roll, pitch, and heading.

The mathematical procedures for accomplishing all this have been worked out at The Mapping and Charting Research Laboratory by Mr. J. B. Schreiter.

The equipment involved is as follows.

1. A star camera.
2. A clock displaying Universal Time.
3. Roll, pitch, and heading indicators from the system under comparison.
4. A doppler navigational system displaying latitude and longitude continuously.

(Items 2, 3, and 4, above are recorded by a data camera.)

5. A PPI radar set and camera.

The star camera, data panel camera and radar camera are all operated simultaneously.

The navigational set and radar mentioned above are used, either separately or together, to produce the latitude and longitude. Since we are concerned with angles in this reduction and not with distance measurements, a very crude value of latitude and longitude produces a relatively accurate space vector. To illustrate, if latitude and longitude are known to within one mile, then the direction of the local vertical can be determined to within one minute of arc, and so on.

We have built a test installation for use in an aircraft which is shortly to be flown. It is a "breadboard" model, and it contains a very bulky aerial camera. I prefer to describe the characteristics of a somewhat more advanced camera system which we are considering. It is a reflective optical system employing two concentric spherical mirrors, one concave (the primary) and one convex (the Cassegrain secondary). It operates with a field of about ten degrees, with an eight inch aperture and twelve inch focal length. Such a system should have star images of the order of 10 microns in diameter on the film, and should photograph fifth magnitude stars in 1/12 of a second, on fast film (Eastman Kodak Company's Royal-X Pan or I-D(2)). The film would have to be held under tension in a curved focal surface, and either 55 mm. or 70 mm. film could be used.

These characteristics are quite remarkable when compared to most existing lens-type optical systems, and we look forward to the increasing utilization of reflective optics in special photogrammetric applications.