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INTEGRATED AIR SURVEY NAVIGATION

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Numerous studies have been made concerning the applicability of the available means for positioning an aircraft during photogrammetric missions. These include various types of radio navigation systems, such as VOR, DME, Loran, Shoran, Decca, Omega, Doppler and others.

Some of these systems, such as VOR and DME have limited range, and even in those areas where usable signals are available, the concept is much more applicable for point-to-point navigation between ground stations than to precision guidance of the aircraft along the tracks defined in a photogrammetric mission. This problem could possibly be overcome by means of a computer-controlled area navigation system, but of course it would require radiomagnetic reference inputs which are not available in all areas.

Doppler, although it is capable of providing stable velocity and relative direction information, requires input of heading information from an external source, and even with the addition of a special computer, does not provide the degree of mission automation which is possible with an inertial track guidance system.

Satellite navigation shows very good promise, but is still a number of years away from being a practical reality.

Longer range radio systems, such as Loran and Omega do not provide the required navigation precision in all cases, due to the effects of propagation anomalies of various types.

A number of attempts have been made to use VLF and/or Omega systems in photogrammetry, with varying degrees of success. Although acceptable relative track guidance may be obtained with these systems under ideal propagation conditions, satisfactory position updating is much more difficult with radio systems. The inherent predictability and repeatability of an inertial platform makes it a definitely superior basis for photogrammetric control. Radio systems providing the very important attitude outputs have yet to be invented.

A comparison of inertial navigation with radio and attitude/heading systems is shown in Figure 1.

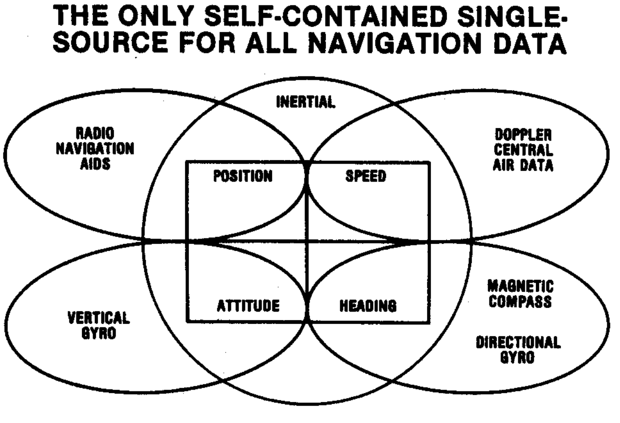

Fig. 1 Comparison of system features

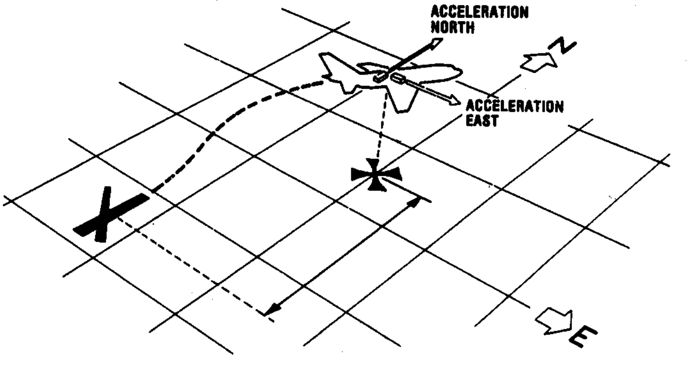

Fig. 2 The accelerometer

INERTIAL NAVIGATION

Inertial Navigation, in its conventional form, is a good system for long range navigation, but is subject to several sources of error, most of which are cumulative, and therefore depend upon the period of time during which the system is operated.

For those who are not familiar with INS, a brief summary of the concept may be in order:

The heart of the INS is a digital computer, which continuously computes position changes of the aircraft. In order to do this, the computer must be given the geographical coordinates of the aircraft position prior to take-off, and thereafter, information regarding direction and distance of aircraft movements must be inputted to the computer to permit continuous calculation of its changes of position. The sensors are accelerometers, which are unidirectional. For that reason, two accelerometers with their sensitive axes 90° apart must be used to measure North-South and East-West accelerations.

The output of each accelerometer is a minute electrical current which is proportional to the acceleration. By the process of electronic integration of the acceleration term with respect to time, we obtain velocity, which in turn is used to determine distance by a second integration. Thus the computer, knowing its point of departure, continuously recomputes present position based on inputs of N-S and E-W movements.

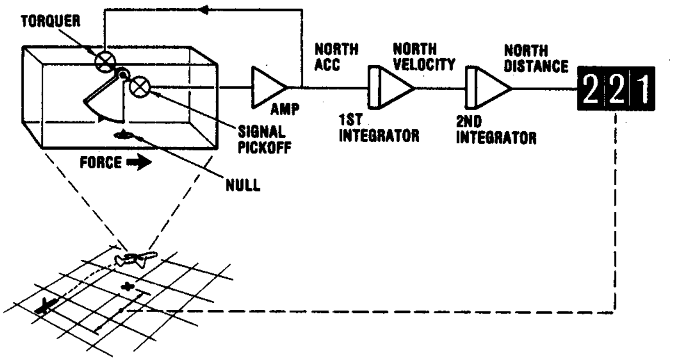

Fig. 3 Accelerometer and integrators

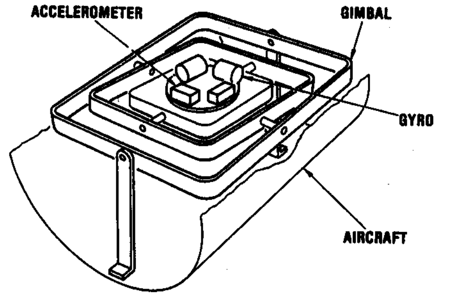

Fig. 4

Gimbals and gyros isolate accelerometers from the effect of earth's gravity

Since the accelerometers are pendulous devices, they must be isolated from the angular attitude changes of the aircraft while in flight which could introduce errors in the acceleration measurements due to the earth's gravity, thus affecting navigation accuracy. The isolation is accomplished by installing the accelerometers on a platform supported by a gimbal set and maintained in a level position by high quality gyroscopes. Although the accelerometers actually measure the aircraft movements, the gyroscopes control the precision of those measurements, and are therefore the principal elements in controlling the system's navigation accuracy.

Gyroscopes tend to maintain their angular position with respect to a point in space. Utilization of this characteristic for control with reference to the normal earth environment requires compensation for two major factors:

1. The earth is an approximately spherical body which is not stationary, but rotates about its north-south axis.
2. The inertial navigation system is usually installed in a vehicle which moves from one place to another over the earth's spherical surface.

Consequently, the inertial navigation system must incorporate two major compensations:

Photogrammetrische Woche 1981
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I. EARTH ROTATION RATE COMPENSATION

Earth rate is sensed by the gyros on the inertial platform, and appropriate torquing signals are applied to the platform to force it to maintain a level attitude with respect to the surface of the earth beneath the platform. This is illustrated in Figure 5.

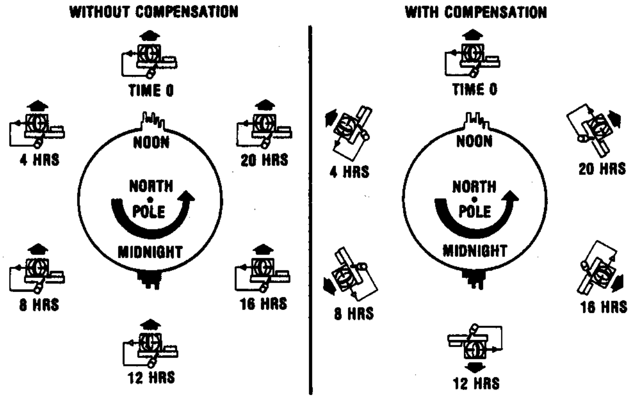

Fig. 5
Earth rotation rate compensation

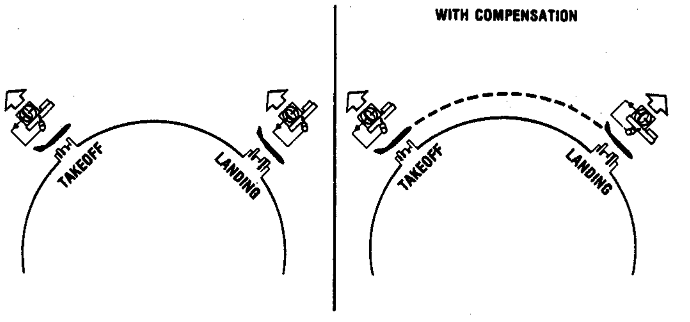

Fig. 6
Transport rate compensation

II. TRANSPORT RATE COMPENSATION

Movements of the aircraft from point of take-off to other locations must also be compensated for. If the earth were flat, such compensation would be unnecessary, but its roughly spherical shape imposes the requirement to sense all aircraft movements and to generate torquing signals to maintain the platform in a locally level attitude with respect to a point on the spherical surface of the earth directly beneath the aircraft. This compensation is illustrated in Figure 6.

Earth Rate and Transport Rate are the two most important compensations in the INS mechanization. The computer program also contains corrections for the fact that the earth is not truly spherical in shape, but rather is an oblate spheroid; for the effects of coriolies, and other factors.

COMMERCIAL INS DEVELOPMENT

The principle of inertial navigation was conceived many years ago. Government sponsored development projects during World War II resulted in practical inertial systems for manned military aircraft and for missiles. A number of test flights were made in commercial airline aircraft during 1965 and 1966, after which the Boeing Aircraft Co. inaugurated the commercial inertial era by incorporating INS into the design of the model 747 aircraft as the primary attitude reference - and as the aircraft's sole means of long range navigation world-wide. Production of commercial INS started in 1968, and to date, more than 5,000 commercial inertial systems have been produced and are in daily use in commercial and military transport and patrol aircraft throughout the world. This is in addition to a total of more than 15,000 inertial systems used in tactical military aircraft.

COMMERCIAL INS CONFIGURATION

The standard commercial INS consists of three basic units:

(1) The Inertial Navigation Unit (INU), which contains the platform with the accelerometers and gyros suspended by a gimbal set; plus the digital computer, and other electronic circuitry for controlling the platform and for processing its outputs.

(2) A Control-Display Unit (CDU) provides a keyboard for entering data; selector switches for controlling system functions; and displays for visual presentation of the computer's outputs.

(3) A Mode Selector Unit (MSU) implements control of the basic operating modes of the system.

Figure 7 shows the three main units which comprise a standard commercial INS.

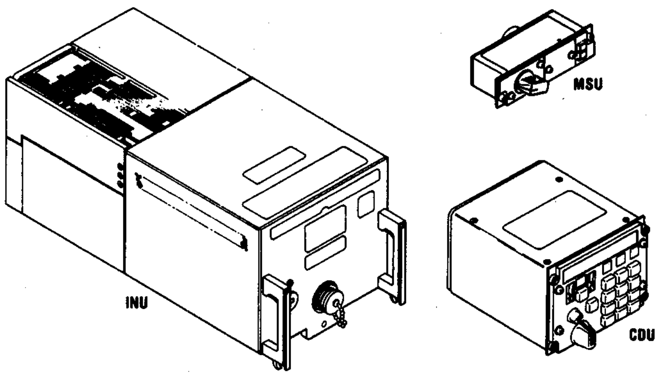

Fig. 7

Commercial inertial navigation unit

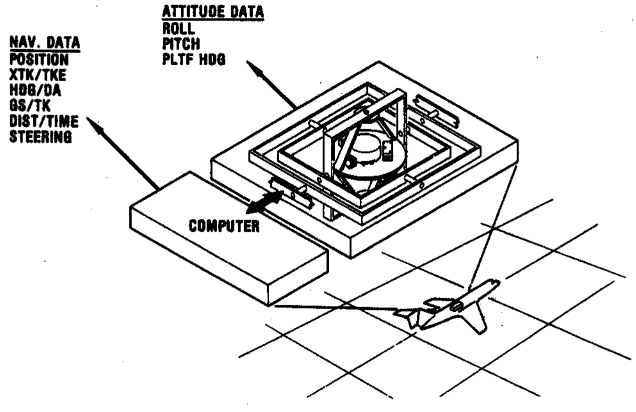

Fig. 8

INS configuration and outputs

Commercial type inertial systems are built to conform to characteristic No. 561 of Aeronautical Radio Inc. (ARINC). In addition to continuously recomputing the aircraft's present position, the system computes, displays and outputs other parameters in analog and digital form to assist in stabilizing, controlling, and navigating the aircraft.

A. Outputs referenced to True North:

Present Position
Track Angle
Ground Speed
Heading
Drift Angle
Wind Direction and Speed

B. Outputs referenced to programmed earth reference points:

Waypoint Coordinates
Desired Track
Distance to Go
Time to Go
Cross Track Displacement
Track Angle Error

C. Analog Attitude Outputs:

Pitch
Roll
Platform Heading

ACCURACY

For long range navigation of transport aircraft, such as transoceanic flights (mostly beyond the range of VOR/DME facilities), the objective of the INS is to guide the aircraft to within the operating range of the short-range facilities at the destination end of the flight. To fullfill this requirement, the Federal Aviation Administration of the U.S. Government has established a specification requiring navigation errors to be no greater than 2 nautical miles per hour of operation in 95 percent of cases (2 sigma). It can be seen that errors of this magnitude could produce a deviation of 20 n.m. from the desired position after a ten hour flight, which is adequate to guide the aircraft within range of a VOR station (approximately 50-75 miles). It is important to remember that the error rate specified is a maximum, and the average rate is usually somewhat lower than one mile per hour. Actual error rates vary from system to system, and from flight to flight. A plot of a number of typical flights with a specific INS system follows the classical Gaussian distribution, as shown in Figure 9.

APPLICATION OF INS TO AERIAL SURVEY

Some important studies of the use of INS for photogrammetry were made in the 1974-1976 time period by the Fokker Company, and by Prof. Corten and Dr. Heimes, then with the ITC. These tests were conducted in an F-27 aircraft equipped with a commercial type inertial system with standard software. A number of updating techniques were developed during that program which significantly reduced the effect of the INS errors and demonstrated that, with appropriate controls, INS could be a viable tool for photogrammetry.

Shortly thereafter Litton Aero Products launched a program to adapt an existing INS design to most effectively fullfill the exacting specifications of aerial photogrammetry and other survey applications requiring precision aircraft track guidance.

An examination of the error sources in an INS reveals that many of them can be controlled to some degree. Since the technology used in the standard commercial INS produces systems which adequately fulfill the long-range accuracy requirements of transport aircraft, however, economic motivation for engineering efforts to achieve additional refinements was lacking. Some classified military development programs have in fact resulted in significant reductions in error rates, but these techniques have not been applied to commercial survey projects because of prohibitively high equipment and software costs, and also due to U.S. Government controls of the technology.

ITGS/PICS

The general name given to the Litton Aero Products project is ITGS (Inertial Track Guidance Systems), and the version designed specifically for photogrammetry is known as PICS (Photogrammetric Integrated Control System).

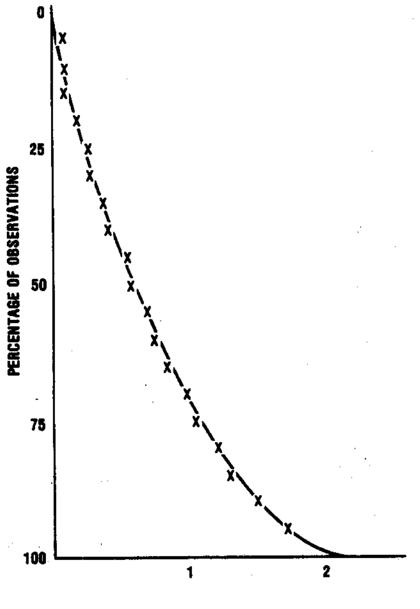

Fig. 9 Typical INS error rate (nautical miles per hour)

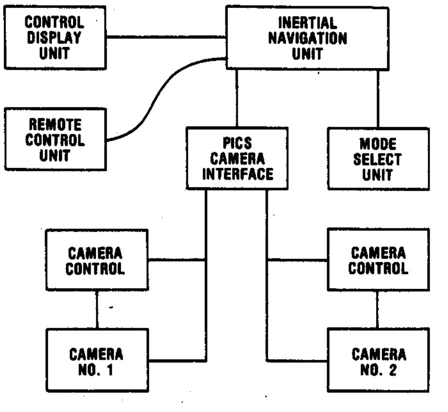

Fig. 10 Block diagram of PICS

ITGS development was actually in progress concurrent with the Fokker program mentioned earlier. It was primarily used to control aircraft engaged in spraying insecticides on the forests in the Canadian province of Quebec, and in the state of Maine, in the U.S.A. The goal was elimination of the spruce budworm which ravaged large areas of forest land. To be effective, the insecticide must be applied very uniformly over the infested area. Application of insufficient quantities of the chemicals did not kill the worms, while excessive applications could permanently damage the trees. Since the aircraft operated at heights of about 50 meters above the treetops, precise control of the separation between successive tracks required specialized techniques. These included procedures for both cross-track and along-track updates, as well as recordings for post-flight reduction among others.

DEVELOPMENT OF PICS

At the beginning of PICS development, valuable suggestions were provided by technical personnel of the ITC, Fokker Aircraft Co., and by the Wild and Zeiss Camera Companies. The first flights of the prototype PICS system were made in 1978 in the Navajo aircraft of the ITC, with assistance by engineers of both Wild and Zeiss. These flights produced inconclusive, but encouraging results.

More comprehensive flight testing of the PICS system was subsequently carried out in Litton aircraft, and in a Brazilian built Bandeirante EMB-110 aircraft of Terrafoto, the photogrammetry agency of the state of Sao Paulo, in Brasil.

The PICS concept as developed during the project uses a production inertial navigation system which has been expanded and adapted by addition of ITGS software and specially designed accessory units to integrate a number of photogrammetry functions which had previously been performed by independent means. Further, it was learned that use of inertial and digital techniques permitted significant improvements in accuracy of some photogrammetric functions, resulting in overall improvement in efficiency, both in the flight operations required to obtain the photographs, and in their later interpretation.

PICS provides all of the basic enroute functions of a commercial INS, including automatic guidance of the aircraft along a great circle track from the airport of origin to the mission area, and in addition, performs the following specialized functions during the mission:

I. Survey Line Track Guidance

- Rhumbline Track definitions
- Automatic Mission Execution
- Visual position updates for pinpoint photography
- Remote navigator-operated aircraft steering
- Human-factored operating procedures

II. Camera Control

- Automatic shutter control for two independent cameras, based upon aircraft position (not time intervals).
- Automatic servoed Drift Angle Compensation
- V/h signals for automatic exposure control

III. Film Data Annotation

- Ten items of information regarding aircraft position, orientation, date, time, and mission identification, plus tilt and tip of the film plane to a calibrated accuracy of two (2) arcminutes for use in laboratory restitution.

The PICS system has evolved into the configuration shown in Figure 10. For economic reasons, an effort was made to utilize standard off-the-shelf INS hardware to the greatest extent possible. An interface unit was designed to condition and reformat output signals from the ITGS for camera controls and data annotation. The remote control unit was added to permit control of system functions by the Navigator from the camera location, including aircraft steering, position updating, and other functions.

In addition to these new accessories, some changes were required in input-output circuits, and the basic computer software was expanded and refined to adapt it to the more exacting requirements of the photogrammetry mission. Software changes included the following:

- Output of LAT and LONG coordinates for aircraft position and navigation waypoints has been tightened from one-tenth of a nautical mile to one one-hundredth (about 20 meters at the equator).
- Resolution of distances and positions used in internal computations has been reduced to approximately 2.5 meters.
- Great circle computation, which is standard for navigation of transport aircraft, is retained for use enroute to and from the survey area, but is replaced during the survey mission by a grid mode using rhumbline computation. This eliminates great circle errors which can be considerable - especially on east-west survey lines at relatively high latitudes.
- Although position updating of INS may not be required for small-scale photogrammetry missions flown at high altitudes (20,000 ft or higher), updating is usually necessary when flying at lower levels. For this purpose the ITGS software provides for storing the coordinates of nine relative position update points in addition to the nine absolute waypoints provided in the basic program.
- Steering equations for commanding the aircraft autopilot have been tightened, and gains tailored to match the dynamic characteristics of the particular aircraft/autopilot combination in use. The special program includes grid separation (distance between survey lines), shutter intervals, and data defining the flight characteristics of the aircraft. Using these data, immediately after the last camera exposure in each survey line, the aircraft is automatically guided through a two-segment standard rate turn to capture the next survey line in a straight and a level attitude. This results in considerable reduction in flying time, with consequent savings in fuel and aircraft maintenance cost.
- The computer program provides for maximum flexibility, permitting the operator to fly the survey lines of a preselected mission flight plan in any desired sequence or direction.

  When the photogrammetry mission is completed, a simple keyboard operation returns the system to great-circle navigation for automatic return to waypoint 1, the airport of the origin of the flight.

CAMERA CONTROLS

In addition to precise control of the aircraft position during a photogrammetric mission, the ITGS/PICS system offers several related, and very useful camera control functions:

SHUTTER INTERVAL CONTROL

The conventional photogrammetric camera is equipped with means of adjusting the interval between exposures by optically measuring V/h or apparent speed, and combining it with desired percentage of longitudinal overlap between pictures and other factors to control an intervalometer. The intervalometer then triggers the camera shutter at precise time intervals, which produces photographs uniformly separated spatially only if there is no wind. If the camera flies upwind on a given survey line, the distance separating consecutive photographs is reduced, and returning down-wind on the next line increases the separation. PICS provides shutter release commands based upon precise spatial position of the aircraft at the time of each exposure. This produces uniform longitudinal overlap between successive pictures, regardless of wind, and good lateral correlation between pictures on adjacent survey lines. Shutter commands are available for two cameras, even though they are equipped with lenses of different focal length.

CAMERA ALIGNMENT

PICS outputs drift angle plus track angle error signals which control a servo motor in the camera to continuously and automatically adjust the camera position in the yaw axis. This assures that the sides of the resulting photographs will always be parallel to the survey line.

EXPOSURE CONTROL

PICS provides apparent speed (V/h) information for those cameras which require it for automatic exposure control.

ITGS GRID PARAMETERS

As stated previously, great circle navigation is used enroute from the airport from which the flight originates to the survey area. A "grid mode" is used to provide specific programmed aircraft guidance and camera control within the survey area. The grid system is built upon a reference line that is given absolute geographic position by the latitude/longitude coordinates of two reference points, known as waypoints 7 and 8 (Figure 11).

To form a Cartesian coordinate system (and provide for along track guidance) a baseline is drawn through waypoint 7 perpendicular to the reference line. The area to be surveyed must be between waypoints 7 and 8. The reference line and all other parallel lines which make up the grid are rhumblines, assuring constant line separation over long survey lines.

Other parameters of the grid mode are:

- Survey Line number - to the left or right of the reference line (line 0).
- Grid Separation - the cross-track distance between adjacent survey lines.
- Shutter Interval - the along-track distance interval between consecutive camera shutter release commands. This distance is precomputed from altitude, lens focal length, and desired longitudinal overlap of consecutive pictures.
- Along Track Offset - the along-track distance between the baseline and boundary of the survey area. Each survey line has its associated along track offset. For zero value, the survey area boundary coincides with the baseline.

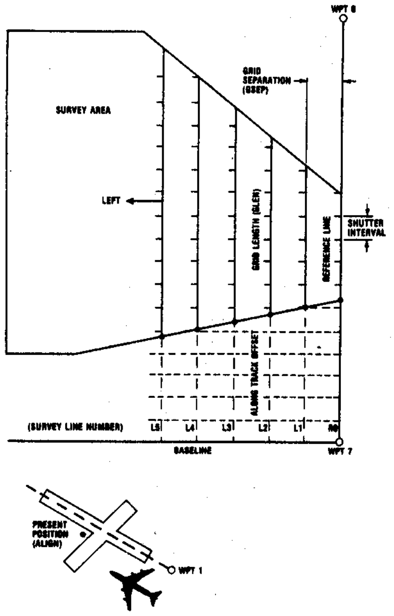

Fig. 11
ITGS grid parameters

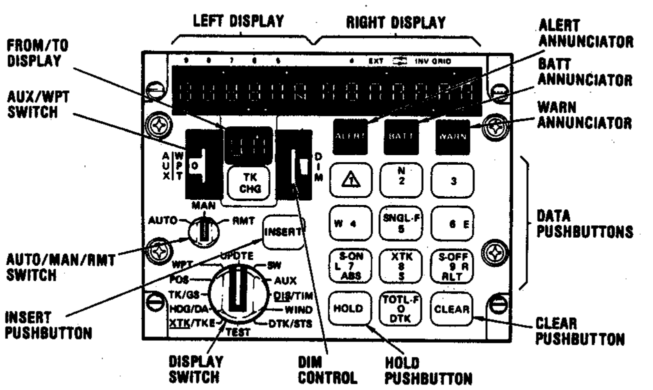

Fig. 12 Control display unit

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Institut für Photogrammetrie
Schriftenreihe, Heft 8, 1982

- Grid Length - The length of each grid line within the survey area.
- Level Point - An artificial waypoint placed on the initial programmed survey line at a specified distance from the start of the survey area for the purpose of allowing time for the aircraft to capture the survey line and to reach a "straight and level" attitude before entering the survey area.

CONTROL DISPLAY UNIT

Figure 12 shows the front panel of the PICS Control Display Unit which is used for controlling the system and entering data.

ALIGNMENT

When the ITGS system is first turned on, it must be aligned. This process, which requires approximately 20-30 minutes, starts with manual introduction of the latitude and longitude of the aircraft position on the ground. The remainder of the alignment process, which is automatic, consists of precise levelling of the inertial platform, and "gyrocompassing", or, determination of the direction from the aircraft position to true north. This is accomplished by the gyroscopes automatically measuring the direction and velocity of the earth's rotation.

While the alignment is in progress the operator, using the keyboard on the Control Display Unit, may select and enter the grid parameters which have been previously defined for the mission to be flown.

Figure 13 illustrates how the system initiates execution of a survey mission.

There are two distinct modes of operation. When the system is first turned on, it is in the normal navigation mode, providing the functions of a standard enroute INS. When the grid parameters for a photogrammetric mission have been programmed, and the system has been so commanded, it shifts to the grid mode, providing aircraft guidance commands and camera controls automatically. Under either autopilot or manual control, the aircraft proceeds to the level point, where it captures the initial survey line and achieves a straight and level flight attitude prior to entering the survey area. Inside the survey area, the camera shutters are commanded to make exposures at preprogrammed spatial intervals.

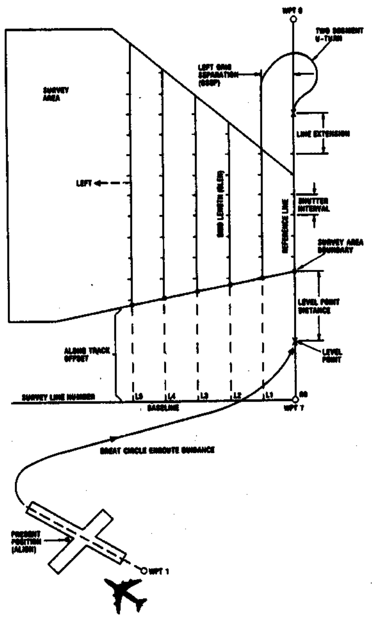

Fig. 13
Starting a survey mission

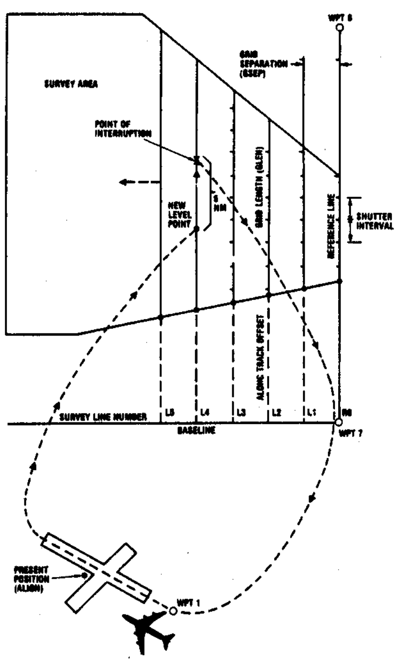

Fig. 14
Grid interrupt and reentry

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Schriftenreihe, Heft 8, 1982

During flight of the first survey line, the operator programs the system with grid length and along-track offset parameters for the next line. This is unnecessary for rectangular survey areas where these parameters do not change. Upon completion of the first survey line and its extension (if one has been programmed) the aircraft is automatically guided through a two-segment turn to capture the second line in a straight and level attitude. This sequence is repeated until the mission is either completed or interrupted by the operator.

Figure 14 illustrates a grid mode interruption and re-entry operation. The operator simply commands the system to revert to normal navigation, at which time aircraft guidance commands are great circle to the airbase, or to a preprogrammed alternate waypoint. At the instant of this operator command, aerial photography ceases, and the system remembers the exact point of interruption. To re-enter the survey pattern, the operator once again selects the grid mode, and the aircraft is guided to a new level point in advance of the point of interruption. When the aircraft reaches the point of interruption, aerial photography resumes and the mission continues without loss of photographs.

REMOTE CONTROL

During flight testing of the PICS system, it was noted that, particularly when the survey area was a considerable distance from the airbase from which the flight originated, the initial flight line (usually the reference line) as commanded by the system occasionally did not coincide with the visually observed flight plan position. This disparity may be the result of inaccuracies in the charts used for flight planning; gyro drift during the flight to the mission area; or a combination of those factors. Previous means of updating required the PICS system to be de-coupled from the automatic pilot, updated, and then re-coupled. If a significant cross-track correction were required to correctly position the aircraft with respect to the first survey line, an excessive time interval could be required for the heading and attitude of the aircraft to stabilize after reconnecting the system to the autopilot.

To solve this problem, a Remote Control Unit (RCU) was developed. The front panel of the RCU is shown in Figure 15.

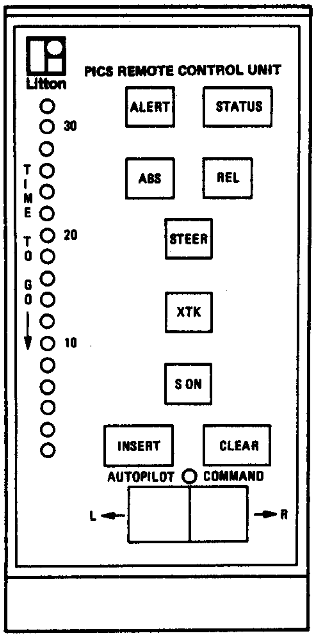

Fig. 15 Remote control unit

This hand-held unit, approximately the size of a digital calculator is connected by a cable to the ITGS computer. It permits the navigator, while observing the aircraft's position through the camera viewing scope, to perform a number of control functions, including:

- Remote Aircraft Steering -

  With the PICS system coupled to the autopilot, the Navigator can take command of aircraft steering by depressing the "steer" key. An LED indicator labelled "autopilot command" illuminates, and the Navigator, using the L-R "rocker switch" at the bottom of the unit, may introduce track angle errors to left or right in increments of two degrees into the system's computer. These commands (maximum 22.5 degrees) produce heading changes of the aircraft through the autopilot. The Navigator, observing position changes through the camera viewer, may at the appropriate moment subtract the track angle errors with the same rocker switch, resulting in an asymptotic approach to the center of the initial survey line, with a minimum of oscillation in either heading or attitude to arrive at the desired survey line in a straight and level attitude. This procedure may also be used if necessary between exposures to maintain the aircraft's position with respect to the programmed survey line.

- Updates -
- Both absolute and relative updates may be performed remotely, using the steering function and the appropriate update keys of the RCU.
- Alert and status annunciators are provided to notify the Navigator if the PICS system is coupled to the autopilot, and whether or not the aircraft is inside or outside the survey area.
- A Time-to-go indicator, on the left side of the unit alerts the Navigator to the imminence of the next exposure, so that repositioning maneuvers, if required, may be performed without affecting photography.

UPDATING

One of the principal error sources in an inertial system is the result of "false accelerations" caused by angular displacements of the inertial platform from the desired "locally level" position. One of the principal contributors to this problem is gyro drift. Figure 16 shows the results of this phenomenon, and the effects of updating.

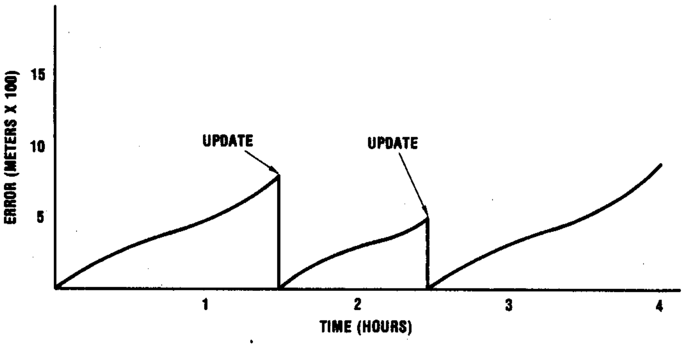

Fig. 16 Effect of accumulated INS errors
(assuming an error rate of 500 meters per hour)

The slope of the curve is related to the drift characteristics of the gyros. The system always starts its operation with minimal errors, based primarily on the accuracy of the present position coordinates entered at the time of system alignment.

In the example shown, an update is made after 1 1/2 hours of operation, eliminating the errors due to gyro drift and resuming operation from a "zero error" position.

Two types of updates may be made with PICS:

- Absolute Updates - position updates made with reference to visual prominences whose geographical coordinates are known.
- Relative updates - position updates with reference to visual prominences whose coordinates are unknown, but which can be positively identified for later use.

Photogrammetry at heights above 6000 meters often does not require updating. When updates are required for missions at lower flight levels, or those requiring maximum precision, the following procedures may be used:

SINGLE RELATIVE UPDATES

After performing an absolute update, a visual prominence may be used for defining a relative waypoint, which can be used as required during the mission for subsequent updates to achieve the required navigation precision.

MULTIPLE RELATIVE UPDATES

Another procedure (Figure 18), involves the use of multiple relative updates to progressively transfer the accuracy of waypoint definition from one location to the next. This is used only in situations requiring very precise definitions of geographic position.

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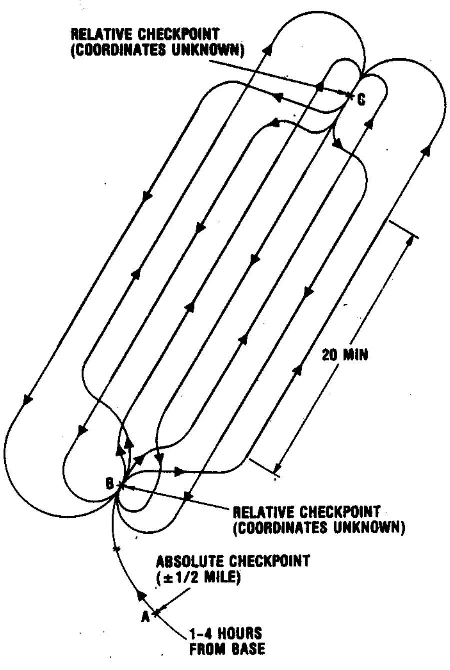

Fig. 17
Relative update procedure

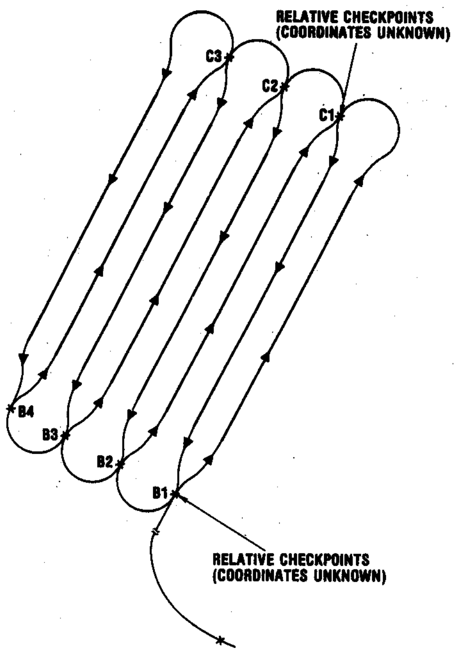

Fig. 18
Multiple relative update procedure

DATA ANNOTATION

The PICS system has been designed to provide annotation of a number of parameters on each frame exposed. This feature was developed in cooperation with Carl Zeiss, in Oberkochen, and with Wild, Heerbrugg. Modifications of cameras to install LED displays are currently available from Zeiss for the RMK series and from Wild for the RC-10. The Wild RC-10A provides LED displays and PICS interfaces as a standard feature.

Figure 19 shows the PICS Interface Unit (PIU) which receives inputs from the inertial system, modifies and conditions them as necessary, and transmits data to the cameras in the correct format for annotation; controls two cameras in the azimuth angle; and controls camera shutters for both interval between exposures and exposure time. Means are provided in the PIU for entering certain annotation data and for monitoring other parameters which are outputted by the PICS system.

The annotation on each frame exposed is continuously recomputed, and includes the following:

Parameter	Resolution
Latitude	0.01 Arc. min.
Longitude	0.01 Arc. min.
Time	0.01 Second
Date	-
Heading	0.1 Degree
Drift angle	0.1 Degree
Altitude	Feet
Pitch (Tip)	0.01 Grads
Roll (Tilt)	0.01 Grads
Identification	-

Although the formats used by Zeiss and Wild are different, the same data are provided in both cameras as shown in Figure 20.

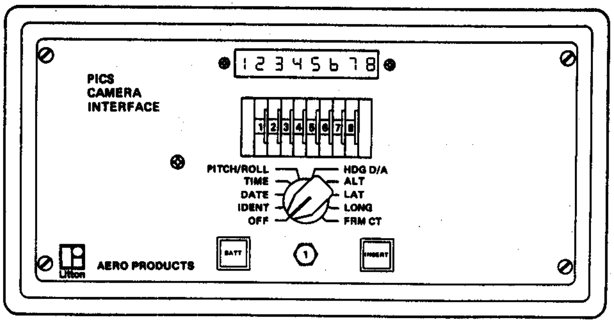

Fig. 19 PICS/camera interface unit

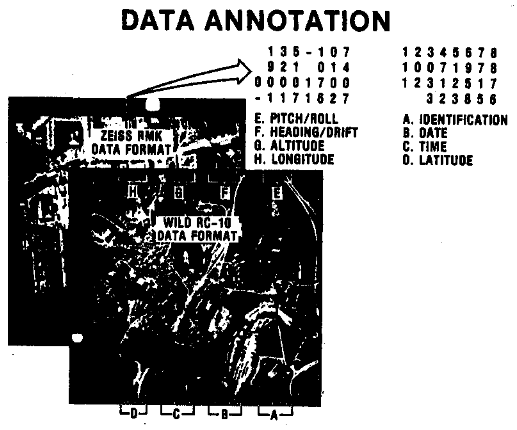

Fig. 20 PICS data annotation formats

SUMMARY

Experience with the PICS system to date has demonstrated its viability for most photogrammetry operations.

The experience of Terrafoto in Brazil shows a significant improvement in productivity in flight operations resulting from use of PICS. This experience was described in a paper presented by Terrafoto's Technical Director, Dr. Raul Audi in Commission I, Working Group 4,at the International Congress of the ISP in Hamburg in July 1980.

The annotation of precise tip and tilt information on each frame also results in important economies. Terrafoto S.A. in Sao Paulo, Brazil,conducted tests using five operators of Wild B8-S equipment to compare orientation time of stereo pairs with and without the PICS tip and tilt annotation. The results, described in detail in a paper presented in Hamburg by Dr. Audi, and Engineers A. Rodrigues and N. Pandelo of Terrafoto show a reduction of more than 30 % in orientation time when the precise tip and tilt information annotation on the film is used.

Adoption of the PICS concept is spreading rapidly. PICS systems are currently in use in Argentina, Brazil, Chile, Mexico, Indonesia, and in the United States. Considerable interest has also been expressed in Australia, Peru, China, and other countries. The ITGS equipments are also in use for radiometric, gravimetric, and other survey operations in Sweden, the U.S.A., and in other countries.

CONCLUSIONS

As a result of experience to date, it may be concluded that:

- Inertial techniques offer a viable solution to navigation requirements for many survey applications.
- The precise measurement of tip and tilt by an inertial platform annotated on each frame photographed can significantly improve efficiency in photogrammetric restitution.
- The use of inertial systems with appropriately programmed digital computers can greatly improve efficiencies of both flight operations and postflight processing in photogrammetric projects.

Photogrammetrische Woche 1981
Institut für Photogrammetrie
Schriftenreihe, Heft 8, 1982

Abstract

The paper summarizes the advantages and disadvantages of various radio navigation systems for use in aerial photogrammetry. The concept of inertial navigation is explained briefly, and the specific hardware and software changes required for adaptation of a standard commercial INS design to fullfill the special requirements of photogrammetry are discussed in detail. The paper specifically describes the Litton "PICS" (Photogrammetric Integrated Control System), and its integrated control of three principal parameters; Aircraft track guidance, Photogrammetric camera controls; and Data annotation on film. Results obtained in photogrammetry missions are described with reference to efficiency of both flight operations and the restitution process.

Integrierte Bildflugnavigation

Zusammenfassung

Der Vortrag stellt zunächst die Vor- und Nachteile der Anwendung der verschiedenen Funknavigationssysteme für Bildflüge zusammen. Das Konzept der Trägheitsnavigation wird kurz erläutert und die besonderen Hardware- und Software-Änderungen werden im Detail diskutiert, die für die Anpassung eines handelsüblichen INS-Systems erforderlich sind, um die besonderen photogrammetrischen Anforderungen zu erfüllen. Im besonderen wird das Litton "PICS" (Photogrammetric Integrated Control System) beschrieben und seine integrierte Kontrolle der 3 Haupt-Parameter: Flugwegführung, Steuerung der Kamera, Datenanzeige auf dem Film. Die Ergebnisse, die bei photogrammetrischen Bildflügen erzielt wurden, werden im Hinblick auf die Effizienz der Flugoperationen und der photogrammetrischen Auswertung besprochen.

Vols à systèmes de navigation intégrés

Résumé

L'exposé traite les avantages et les désavantages de différents systèmes de radionavigation réalisés au cours de photovols. La conception de la navigation par inertie est brièvement expliquée. L'auteur présente les changements du hardware et du software entraînant des adaptations d'un système de navigation intégré (INS) aux exigences particulières de la photogrammétrie. Une description détaillée donnée du "PICS" (système de commande intégré photogrammétrique) de Litton ainsi que de la commande des 3 paramètres principaux suivants: contrôle du trajet de vol, commande des chambres photogrammétriques, données supplémentaires sur le film. En plus l'auteur fournit des résultats de vols photogrammétriques relatifs à une navigation optimale et à une restitution efficace.

Navegación integrada de vuelos fotogramétricos

Resumen

En la conferencia se exponen en forma condensada las ventajas y desventajas de varios sistemas de radionavegación en cuanto a su uso para la fotogrametría aérea. Se explica brevemente el concepto de navegación inercial y se discuten con todos sus detalles las modificaciones específicas de los hardware y software necesarias para adaptar un sistema de navegación inercial de tipo standard y corriente en el comercio de modo que cumpla con las exigencias particulares de la fotogrametría.

Se describe especialmente el PICS (Sistema de mando fotogramétrico integrado) de la casa Litton así como el mando integrado de los tres parámetros principales: guiado de la trayectoria o pasada del avión, mando de la cámara fotogramétrica e impresión de los datos en la película. Se describen los resultados obtenidos durante las misiones fotogramétricas, tanto en lo referente a la eficiencia de la operación de vuelo como la del proceso de restitución.

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