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DEFENSE MAPPING AGENCY INERTIAL POSITIONING SYSTEM TEST RESULTS--ETC(U)
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In 1979, the U.S. Defense Mapping Agency received its second inertial surveying system, which was built for DMA by Honeywell, Inc. The system has undergone extensive field testing in both a vehicle and a helicopter. This paper describes the system, details the field test procedures, and describes the results that have been obtained with this new system. The operational evaluation of the system includes many static and dynamic tests under various conditions and scenarios, designed to answer the classical questions such as effect of length of travel time between zero velocity

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Defense Mapping Agency Second Inertial Positioning System Test Results

by

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DEFENSE MAPPING AGENCY

SECOND INERTIAL POSITIONING SYSTEM TEST RESULTS

By Harry C. Harris

ABSTRACT

In 1979, the U.S. Defense Mapping Agency received its second inertial surveying system, which was built for DMA by Honeywell, Inc. The system has undergone extensive field testing in both a vehicle and a helicopter. This paper describes the system, details the field test procedures, and describes the results that have been obtained with this new system. The operational evaluation of the system includes many static and dynamic tests under various conditions and scenarios, designed to answer the classical questions such as effect of length of travel time between zero velocity updates and between survey update points, value of single versus double runs, sensitivity to directional changes, and comparison of results obtained in a vehicle and a helicopter.

I. INTRODUCTION

In 1975, the U.S. Defense Mapping Agency (DMA) accepted delivery of its first inertial positioning system (IPS-1). That system was built by Litton, Inc., who subsequently marketed the system under the name Autosurveyor. The testing and utilization of that DMA IPS-1 have been previously reported.[1,2,3,4] Honeywell, Inc., delivered the second DMA inertial positioning system (IPS-2) in 1979. Honeywell refers to this system by the name Geo-Spin. The primary purpose of this paper is to report on the tests that have been performed on IPS-2 and the results of those tests as they impact on system capabilities.

2. DESCRIPTION OF THE SYSTEM

The electrically suspended gyroscope (ESG) technology employed in the Honeywell SPN/GEANS platform and IPS-2, and the adapting of this basic navigation technology to use as a geodetic survey instrument, have been well reported.[5,6,7,8,9] Some IPS-2 test results have been reported by M. J. Hadfield.[10,11] Only a brief description is given here. IPS-2 combines the basic inertial measuring unit (IMU) and electronic assembly unit (EAU) with a ROLM 1664 computer of 64K memory and its computer control unit; a Termiflex Model HT/4, 24-character display 60-function keyboard, hand-held control and display unit for operator control of the system; a system interface unit; a power conversion unit to change the 28-volt DC input to that required; a Qantex 2200 data storage unit with two tape drives; a 256-character IEE Argus Maxi-256 remote display unit; a K&E Autoranger Model 76 D332 electronic distance measuring instrument for eccentric observations; a Texas Instruments Silent 700 KSR 743 for hard-copy output and alternate input; a Gibralter pan and tilt head to permit pointing of the entire IMU when making eccentric observations; and cables, batteries, blowers, fixtures, racks, and brackets. The minimum essential weight of the system is about 200 kilograms, and the maximum weight is approximately 270 kilograms with all options and mounting hardware. IPS-2 requires up to 100 amperes of current at 28 volts DC during premission warm-up and alignment. The power requirement reduces to about 62 amperes during routine operations.

It is not necessary for the system to be able to directly occupy the survey stations. The rotation and pitch capability of the pan and tilt head permit the operator to align the IMU (actually the Autoranger) to a reflector placed on the survey station, and to measure the slope distance to the point. This slope distance, together with pitch, roll, and azimuth information, is automatically fed to the on-board computer for the computation of the eccentric reduction.

The system survey program permits real-time updating of position, elevation, deflection of the vertical, and gravity on an opportunity basis. The system can perform an adjustment of each of these parameters as long as at least two updates of the parameters are given somewhere in the traverse. There are 99 memory locations available for storing survey data. These 99 computer memory locations can be used to increase productivity and decrease operator errors. Before the survey begins, the operator can record on tape the station identifications, known or approximate survey values, and a code to indicate which survey parameters are known at each station. These tapes become survey tables that are read into computer memory, as required, before each particular survey for which they are designed. This provides a steering capability and verified update values. The operator is free to modify the survey table as required as the survey progresses. The use of the preplanned survey table on tape reduces the amount of data to be entered by the operator, permitting the survey to proceed more rapidly with less chance that the operator will make an error. The system permits the operator to read the recorded survey data back into the computer memory, correct errors in station identification and survey parameter update values, adjust the corrected data, and create a corrected magnetic tape.

One of the primary differences between the operation of inertial systems for navigation and for geodetic surveys is the use of zero velocity updates (ZUPTs) during surveying. Typically, the system is stopped every 1 to 5 minutes during the survey, depending on the accuracy desired, for a period of 24 seconds for a ZUPT to be performed.

3. SYSTEM CALIBRATION

There is no requirement for dynamic field calibration over a known calibration course. All system calibration except VMU (velocity measuring unit) calibration, which is discussed later, is accomplished about once a year in a static mode. The annual calibration cycle requires about 61 hours. All the calibration information is accumulated in computer memory and is recorded on magnetic tape for daily use during the surveys.

On a daily basis, the system requires from 60 to 120 minutes to prepare for a survey from a cold start, depending on whether or not a VMU calibration is desired. The VMU calibration cycle can be eliminated if the gravity vector recovery is not of interest and if optimum results are not required for the other parameters. The latest VMU calibration data are stored on magnetic tape and continue to be used until superseded by a new calibration. IPS-2 contains the speed control option, which means that the system can operate indefinitely without being shut down. This also means that the 60-minute premission warm-up and alignment time is virtually eliminated and the VMU calibration, if desired, can be accomplished during breaks between shifts.

4. PRELIMINARY TESTS

A 6-hour series of static ZUPT tests was run. The nominal ZUPT intervals were varied between 2, 4, and 8 minutes. The "park period," or amount of time in each ZUPT, was 20 seconds. The delta northing, delta easting, and the elevation were analyzed for each ZUPT interval for each test. The data are tabulated in Table 1, and plotted in Figure 1. Figure 1 contains an additional plot point furnished by Honeywell from tests run at their facility. The results are as expected; the shorter the ZUPT interval, the better the accuracy.

A static test was executed to determine if rotating the IMU to different headings would cause a change in the survey results, either a discontinuity or change in scatter. Constants of 220 seconds between ZUPTs and 20 seconds of park time were used. The heading of the IMU was changed by 90° every 30 minutes. The heading sequence was N, E, S, W, N, E, S, W, N. Three days later the test was repeated without rotating the IMU. The two test sequences were compared. There was no significant difference between the results. The conclusion is that there is no significant system heading sensitivity.

Studies were conducted using the eccentric station technique. An east-west line was laid out and a triple prism set on a concrete monolith at the east end of the line. The system was moved a total of 420 meters west along the line at distance intervals of about 40 meters as eccentric measurements were made back to the prisms. The peak Autoranger signal was used for pointing. The changes in the computed latitude, longitude, and elevation of the prism station were plotted as functions of distances from the prisms. The azimuth error (latitude) was scattered over a range of ±50 cm in a random fashion. This indicates the need for a better sighting device than the Autoranger signal. The elevation and longitude errors ramped as functions of distances from the prisms, indicating systematic errors in the alignment of the Autoranger to the IMU or errors in the computer program. The K&E Autoranger was tested over a known distance and verified. Until the problem is resolved, the maximum allowable eccentric distance is 20 meters.

5. ACCEPTANCE TEST

The acceptance test course is the major north-south portion of the overall test area shown in Figure 2. The overall length (one-way) is 65 kilometers. Latitude, longitude, elevation, deflection of the vertical, and gravity are known at each survey station. Some stations have azimuth marks. The acceptance test was executed in a vehicle. Nominal ZUPT intervals of 4 minutes were used, with single ZUPTs of 20-seconds duration. Ten double-run traverses (015 to 180 to 015) were accomplished, with a short alignment at each end. VMU calibration was not used. The actual one-way total elapsed time was about 2 hours. In each run, stations 015 and 180 were used as update (known) stations, and all other points were considered to be unknown. The system's on-board computer was used at the end of each leg to adjust, or smooth, the survey, using the error of closure on the known station. The raw and adjusted IPS-derived survey parameters were recorded on magnetic data cartridges.

For each of the 10 double runs of the test course, the IPS-derived survey values for each station on the out leg were meaned with the values obtained on the back, or return, leg. These mean IPS-derived survey values were compared with the known values for stations 115 through 175 and the RMS error determined for each double run. Attempts to transfer azimuth from a Porro prism mounted on the IMU case were not successful in runs 1 and 2. In runs 3 through 10, IPS-2 was used to establish the positions of azimuth marks about 500 to 1000 meters away, using 1 minute between ZUPTs from the primary stations to the azimuth marks. The azimuths between the primary stations and the azimuth marks were computed by inverse methods. A theodolite was used to transfer azimuths from conventional azimuth marks to the new IPS-established marks for comparison during each run. The acceptance test results are illustrated in Table 2 for each run and for the aggregate. The a priori estimates of the test course errors were ±15 cm for latitude and longitude, ±3 cm for elevation, and ±10 seconds for azimuth. Several significant elevation errors were discovered in the test course. These have been corrected in the illustrated test results. The acceptance test requirements of ±1 meter and ±30 seconds, RMS, were easily met by the system.

The test results were recomputed as if station 145 had also been "known" and used for updates at the approximate halfway point of the test course. Those computations yielded an RMS value of ±22 cm for a double run over the same test course divided into two 32 kilometer, 1 hour legs one-way, after correction for test course errors.

The single run (one-way) RMS value for the 65-kilometer course was about ±74 cm. These same data treated as 32-kilometer traverses yielded ±48 cm accuracy for a single run.

The gravity vector was not an item of primary concern in the procurement and testing of IPS-2. As a matter of interest, the IPS-derived values for deflection of the vertical and gravity, after smoothing, were compared with the known values. The double run gravity and deflection accuracies, respectively, were ±10 mgal and ±4 seconds, RMS, without the use of daily VMU calibrations.

The raw data showed a scale factor error of about 1 part in 27,000 and an average alignment error of about ±60 seconds in the system. The actual alignment of ±60 seconds, compared to an expected typical ±12 seconds self-alignment capability, causes a great deal of concern. It can also be seen in reviewing the test data that the scatter of the results was larger than expected. This may be attributed, in part, to poor system calibration.

6. HELICOPTER TESTS

The complete IPS-2, except pan and tilt head, was installed in a Bell Jet Ranger II model 206-B helicopter. The system was flown under various imposed conditions over selected stations of the same test course used for the acceptance test. The various conditions of each run and the results are summarized in Table 3.

With the number of variables involved in a test such as this, it is difficult to evaluate all factors. The following conclusions are fairly obvious: the use of the double ZUPT technique yielded the best results; the runs where no turns of the helicopter were made were consistently better than everything except the double ZUPT runs; the actual hover runs yielded the worst results, as expected, but had unexplained good latitudes and bad longitudes; the very hard turns were no worse than the single 180° turns in and out; the results in landed hover mode were slightly better than in the landed ground mode; and using the mean values of a double run improves the accuracy of results by 33% compared to single runs. While not illustrated by the Table 3 data, the system exhibited the same relatively gross alignment problems and scatter of data during the helicopter tests as had been experienced in the acceptance test.

After considering the variety of conditions, some of which were unfavorable, that were imposed on the system during the helicopter tests, it is surmised that the results are comparable to those obtained in the vehicle-borne acceptance tests if the helicopter is landed for ZUPTs and marks and if turns are kept to a minimum. The use of double ZUPTs improves the accuracy. This method of operation has not been tested in the vehicle. The one-way survey in the vehicle requires about 2 hours and in the helicopter about 40 minutes. The environment of the helicopter apparently degrades results more than the vehicle. The end result is that the helicopter allows one to perform the same survey to the same accuracy in considerably less time.

7. "L-SHAPED" TESTS

That portion of the Figure 2 test net that begins at station 038 and goes to station 120 by way of 015 was used for "L-shaped" tests. Updates were performed at 038 and 120 only. The overall test results yielded position and elevation RMS values of ±41 cm and ±35 cm, respectively, for a double run, and ±54 cm and ±40 cm for a single run.

The one-way test course length is about 30 kilometers and requires about 1 hour in the vehicle. This length between updates is about the same as half the acceptance test, and is expected to yield a double-run accuracy of ±22 cm. It actually yielded an RMS accuracy of ±38 cm. The problem seems to be associated with the impact that the alignment errors and apparently poor calibration have on a nonstraight traverse. Although static tests showed no apparent heading sensitivity, the result is the same as if heading sensitivity did exist.

8. FIGURE 8 TESTS

The test course was observed with an update at station 015, then stations 105, 110, 210, 310, 315, 320, 220, 120, 115, 110, 210, 310, 305, 022, and 018 were observed, in turn, and a closing update was made at 015. This is a 60-kilometer distance. A preliminary look shows that the smoothed data are about the same quality as the raw data, or about ±5 meters RMS, for a single run for position and ±1.5 meters for elevation. It is obvious from the data that the loop closure is the worst survey design.

9. SUMMARY AND CONCLUSIONS

The IPS-2 hardware has been generally satisfactory, although it is rather heavy and requires considerable power. One of the major deficiencies is the nickel-cadmium rotor support battery, which should be replaced with a more reliable power source. A more visible remote display unit is required, or a miniature remote display unit for the pilot should be added.

The software was adequate enough to successfully pass the acceptance test, but certainly can be greatly improved. The Kalman filter option was tested and found to degrade results. The poor alignment (gyrocompassing) is probably a software problem, which may be directly related to the poor, erratic calibration. The algorithm for resetting the gravity vector during ZUPTs may be faulty. Certain operator functions are very subject to human errors, which can result in loss of data. The gravity vector accuracy is several times worse than was expected at this stage of development. The K&E Autoranger has the potential for performing relatively long offsets to eccentric stations, but apparent hardware problems or software errors are now limiting its use to a maximum of 20 meters.

At the time this is being written, the system is in the hands of Honeywell for the purpose of performing 4 hardware repairs and making 14 specific software changes, some of which have been completed. The results to date are very encouraging. The static tests are yielding the best results ever achieved. The limited field data taken with some of the modifications included are showing a 2 to 1 improvement in position results, a 3 to 1 improvement in deflection of the vertical, and up to a 10 to 1 improvement in the gravity magnitude accuracy. The software modifications scheduled for this time period will be completed shortly, and field test data will be collected and documented for comparison with previous results. There are several other software areas that are being looked into now or will be investigated further during the next year.

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TABLE 1

IPS-2 STATIC ZUPT TESTS

LENGTH OF TEST (MIN)	DATE (1979)	ΔT (sec)	SIGYX (CM) ΔN	ΔE	ΔH	Remarks
360	1 Oct 79	150	6	8	5	60 minutes each ΔT.
		270	26	19	18	
		510	82	44	58	
		510	71	66	33	
		270	14	26	21	
		150	4	6	5	

TABLE 2

RESULTS OF ACCEPTANCE TEST

RUN NO.	RMS ERROR (CM) LAT.	LON.	ELEVATION	RMS ERROR (SEC) AZIMUTH
1	101	81	26	NA
2	105	74	67	NA
3	56	74	35	4.4
4	41	52	68	7.6
5	59	58	91	9.4
6	32	26	26	13.1
7	35	35	44	13.1
8	29	58	24	10.9
9	120	21	127	15.1
10	48	32	18	6.7
TOTAL RMS	70	55	59	11
COURSE ERROR	15	15	3	10
NET ERROR	68	53	59	5

TABLE 3

SUMMARY OF HELICOPTER TESTS

DATE (1979)	RUN	ZUPT INTERVAL (MIN)	MODE: GROUND LANDED	MODE: HOVER LANDED	MODE: HOVER HOVER	DOUBLE RUN ACCURACY* RMS (CM): LAT	DOUBLE RUN ACCURACY* RMS (CM): LON	DOUBLE RUN ACCURACY* RMS (CM): ELEV	SINGLE RUN ACCURACY* RMS (CM): LAT	SINGLE RUN ACCURACY* RMS (CM): LON	SINGLE RUN ACCURACY* RMS (CM): ELEV	REMARKS
6 NOV	1	4	X			(64)R	(227)R	(54)R	(146)R	(239)R	(112)R	OPERATOR REJECTED DUE TO INITIALIZATION ERROR
	2	4	X			26	32	23	58	42	62	NO TURNS.
7 NOV	3	4	X			42	73	19	51	114	85	NO TURNS.
	4	4	X			86	61	31	48	72	36	NO TURNS.
	5	4	X			66	56	52	88	60	88	NO TURNS.
	6	4	X			40	54	42	58	80	48	NO TURNS.
8 NOV	7	4	X			48	98	58	116	102	76	HARD 540° TURNS BEFORE EACH STATION.
	8	4	X			51	44	89	94	60	108	HARD 540° TURNS BEFORE EACH STATION.
	9	4	X			45	67	55	52	70	70	NO TURNS OUT LEG, 180° TURN IN/OUT ON BACK LEG
10 NOV	10											DIFFERENT TEST COURSE.
11 NOV	11	4	X			35	153	27	116	184	86	NO TURNS OUT LEG, 180° TURN IN/OUT ON BACK LEG
12 NOV	12	4	X			64	88	133	207	112	140	NO TURNS OUT LEG, 180° TURN IN/OUT ON BACK LEG
	13	4	X			91	128	54	127	136	73	NO TURNS OUT LEG, 180° TURN IN/OUT ON BACK LEG
	14	4	X			93	59	77	94	122	78	NO TURNS OUT LEG, 180° TURN IN/OUT ON BACK LEG
	15	4	X			40	56	60	54	106	65	NO TURNS OUT LEG, 180° TURN IN/OUT ON BACK LEG
13 NOV	16	4	X			132	94	73	196	195	88	NO TURNS OUT LEG, 180° TURN IN/OUT ON BACK LEG
	17	4		X		84	93	29	84	98	140	NO TURNS OUT LEG, 180° TURN IN/OUT ON BACK LEG
14 NOV	18	4	X			74	62	39	95	200	123	NO TURNS OUT LEG, 180° TURN IN/OUT ON BACK LEG
	19	4		X		42	58	34	59	136	136	NO TURNS OUT LEG, 180° TURN IN/OUT ON BACK LEG
	20	4		X		20	32	34	58	40	106	NO TURNS OUT LEG, 180° TURN IN/OUT ON BACK LEG
15 NOV	21	4			X	82	135		65	145		HOVER ZUPTs AND MARKS, LANDED UPDATES.
16 NOV	22	4										DIFFERENT TEST COURSE.
	23	4			X	59	169		76	170		HOVER ZUPTs AND MARKS, LANDED UPDATES.
17 NOV	24	4										DIFFERENT TEST COURSE.
	25	4		X	X	52	111		74	114		HOVER MARKS, LANDED ZUPTs AND UPDATES.
18 NOV	26	4		X	X	42	140		83	135		HOVER MARKS, LANDED ZUPTs AND UPDATES.
	27	3	X	X		77	101	99	64	99	96	FULL ACCEPTANCE TEST COURSE.
	28	2		X		83	163	17	92	166	158	SHORT INTERVAL BETWEEN ZUPTs.
19 NOV	29	4	X			15	39	17	34	176	75	DOUBLE ZUPTs.
	30	3	X			46	31	37	80	122	60	FULL ACCEPTANCE TEST COURSE.
	31	4	X			25	43	54	50	82	58	DOUBLE ZUPTs.
						56	82	50	83	115	89	OVERALL.
						50	53	33	59	72	64	NO TURNS.
						48	69	74	104	80	92	HARD TURNS.
			SUMMARY**			67	80	62	113	138	87	GROUND LANDED, MIXED TURNS.
						59	88	43	69	107	127	HOVER LANDED, MIXED TURNS.
						57	139		75	140		HOVER HOVER, MIXED TURNS.
						13	38	36	39	128	66	DOUBLE ZUPTs, MIXED TURNS.

*NO COMPENSATION FOR TEST COURSE ERRORS.
**COMPENSATED FOR TEST COURSE ERRORS.

TABLE 3. Summary of Helicopter Tests

NORMAL ZUPT INTERVAL (MIN)	AVERAGE STANDARD DEVIATION (CM)
2	7
4	25
8	59

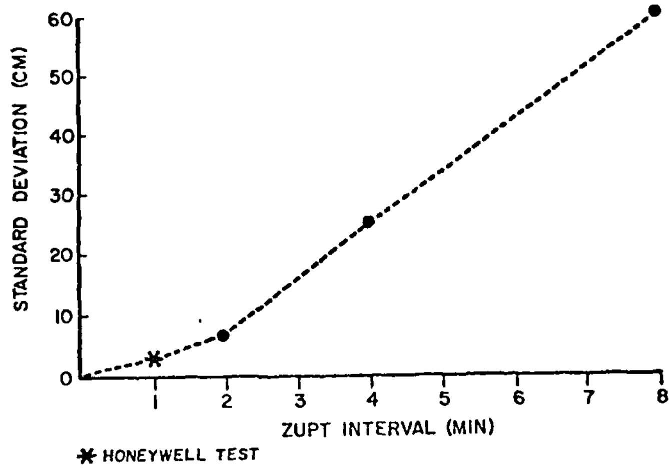

Figure 1. Static ZUPT Test Results

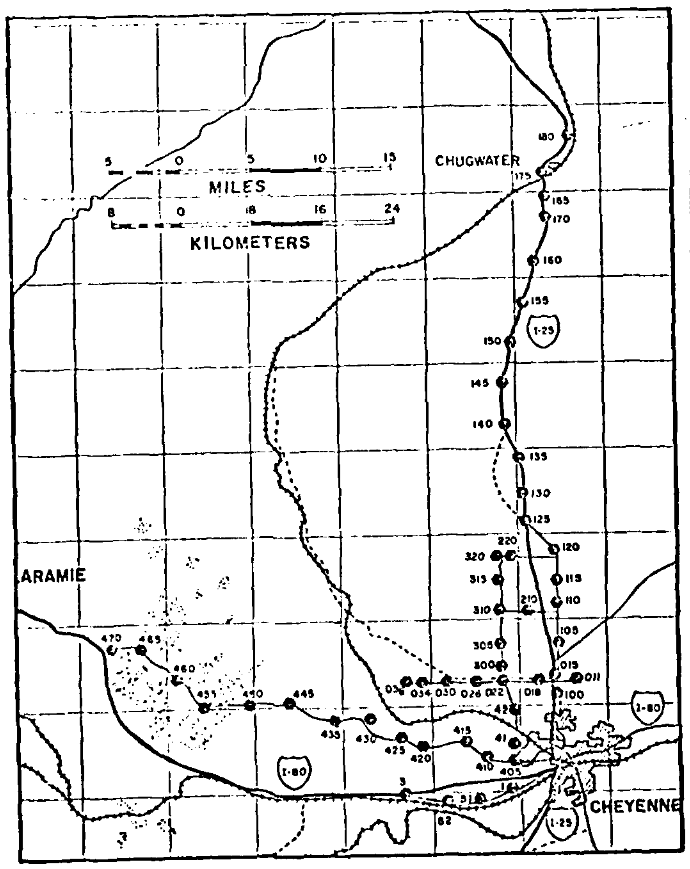

Figure 2. IPS Test Courses

Biography of HARRY C. HARRIS

Harry C. Harris is a Geodesist in the Techniques Office of the U.S. Defense Mapping Agency (DMAHTC), Geodetic Survey Squadron, where he performs operational testing and evaluation of new survey systems and conducts studies to resolve operational problems. He has specialized for the past few years in Doppler and inertial systems, and is a former member of Special Study Group 2.44 of the International Association of Geodesy.

Mr. Harris received his B.S. in Civil Engineering from the Georgia Institute of Technology and also studied at North Georgia College and Rollins College. He served 4 years in the U.S. Air Force, and did field work in Nicaragua and Haiti with the Inter American Geodetic Survey before joining the Geodetic Survey Squadron in 1961.

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