II. CRUISING AND POSITIONING BY NNSS

By Junsuke Chujo and Fumitoshi Murakami

Introduction

During the present cruise, NNSS (Navy Navigation Satellite System) and Loran C were applied to fix the positions and to navigate. Loran C was received by the LR-3Z1 of Furuno Electric Co. This is a full electronic automatic tracking devices with attached XY plotter. The SS3 Loran C chain was used near Japan and the S3 chain near the Hawaiian Islands. The surveyed area was, however, just to the rear of the station on Johnston Island, and it did not give good position fixes because of the bad crossing angles of lanes in hyperbolic operation. Thus, Loran C was only of auxiliary use during this cruise, and NNSS played the important role in cruising and positioning. This article will be concerned with the technical problems of observation by NNSS, particularly with regard to the field status of the satellite fixes and the errors of dead reckoning.

NNSS was manufactured by Magnavox Co. and it is called Model 200 designed for geophysical use. This system has already been discussed in other papers (Stansell, Jr., 1968; Mizuno and Chujo, 1974 and Chujo, 1974).

Observation conditions

As the surveyed area is very deep, the EM Log was applied as the speed sensor, because the doppler sonar could not be applied in deep water by bottom lock mode and did not always work well by water tracking mode. Because the EM Log was the speed sensor for water, the accuracy of dead reckoning was less than that of the bottom lock mode. Values for water speed and water heading were put in advance into the NNSS computer as instruction WSPD and WHDG respectively. WSPD and WHDG values were calculated from the S-UPDATE value which is the difference between the last updated satellite fix position and the dead reckoning position.

The outputs of the NNSS system are as follows.

1. A high speed printer is used for input and control, and all output except gravity data.
2. A teletype writer is used for the processed gravity data output.
3. Two magnetic tape mechanism record the digital data alternatively.
4. CRT monitors show navigational data as real-time data display.

Printed paper is used for control and data monition. The magnetic tapes are used for geophysical studies through the process computer. CRT displays are mounted at the near NNSS console, chartroom, geological and geophysical laboratories. Fig. II-1 shows the example of display. The NNSS system is used not only for position fix but also for data aquisition system.

Satellite fix

The NNSS system operated fairly well in this cruise. Three times in 66 days the receiving system stopped. Once the program halted naturally. In the other two cases the program halted when the computer had been used for other jobs such as ALERT computation. At this time the memories of computer were normal, and when the operator designated the starting address of 6 again, the program restarted normally. After restart-

Fig. II-1 CRT display.
Navigational data are displayed on the CRT in real-time. DC: the distance cross course, GMT: Greenwich mean time, LAT: latitude, LON: longitude.

ing the time was set to current time by the instruction TIME and the azimuth IHDG set to the current direction of the gyrocompass.

The navigation program was kept normally in memories. At one time gravity program was destroyed, the reason not being clarified. The program was loaded again and restarted.

When the satellite receiver receives the satellite waves of 400 MHz and 150 MHz, it detects the doppler shifts and satellite information and the computer calculates the position. This is the satellite fix. The satellite fix, however, does not always give an accurate position. There are seven acceptance criteria which satisfy accurate positioning. The next seven criteria are "AND" relation.

1. Iteration ...... 5 or less. (convergence of computation)
2. Elevation angle ...... 15 to 70 degrees.
3. Doppler symmetry ...... message sync two minutes or more before the center of pass.
4. All doppler counts must be within a certain threshold of error.
5. UPDATE-AUTO/MAN switch on Interface Unit (model 200) front panel is in AUTO.
6. A minimum variance must be meet.
7. There must be refraction corrected fix. (refraction of electric waves in the iono-

sphere)

Through the seven criteria listed above some satellite fixes update automatically and exchange the new position fixed to the dead reckoning position. Others are not updated and the printer writes N-UPDATE. But some no-update data, which look reasonable, are updated manually. When the time is long from the last fix and/or the current position is not so accurate for some reason, no-update satellite fix turn to manual update. The criteria of iteration and elevation angle are always kept. As NNSS satellites keep the polar orbit, even if the elevation is too low or too high, the accuracy of Latitude keeps good and the one of Longitude is bad. So the instruction can update only Latitude. But ULAT was rarely used in this cruise.

The satellite fixes during the cruise from Chiba Harbour (Tokyo Bay) to Honolulu are listed in Table II-1, during 12 days from the 226 day (Aug. 14th) to the 238 day. In this table, A is Auto-Update, M is Manual-Update and N is No-Update. The statistics, used 11 days data between 227 day to 237 day, are shown in Table II-2. The average receiving time was 24.7 times per day, so the average interval is 58 min. The average of the Auto-update is 14.0 times and 56.7%. Manual-update is 3.73 times and 15.3%, then all of update is 71.7%. No-update is 7.0 times and 28.3%. The average interval of A-update is 1 h 43 m, but in actual field work more than 6 h has been sometimes required to A-update. On the 229 day, for example, the longest waiting time was 6 h 24 m between 0900 to 1524, which is shown later. During this interval 3 satellite fixes were manually updated and other 3 satellite fixes are not updated. Some times the good elevation satellite passes are followed after the bad one regretfully.

The statistics were calculated for the cruise from Honolulu through the surveyed area

Table II-1 Number of satellite fixes between Chiba to Honolulu.

Day	A	M	N	R	Remarks
226	2	6	3	11	Departure; 14 h, Chiba Harbor
227	11	7	12	30	226 day is Aug. 14th.
228	19	2	5	26	
229	13	5	5	23	Sat fixes of 229 day are
230	16	4	10	30	shown on the other table.
231	7	11	10	28	
232	16	3	4	23	approximate positions:
233	18	1	2	21	Chiba Harbor: 35N, 140E
234	10	4	10	24	Honolulu: 21N, 158W
235	13	4	4	21	
236	16	0	8	24	
237	15	0	7	22	
238	1	—	—	—	Arrive Honolulu

Day: Julian calender day, A: Auto-update, M: Manual-update, N: No-update, R: Receiving times of satellites

Table II-2 Average and percentage of satellite fixes on 11 days of Chiba to Honolulu cruise.

	A	M	N	R	Remarks
Total	154	41	77	272	of 11 days
Average	14.0	3.73	7.0	24.73	per day
Percentage	56.7	15.0	28.3	100%	

Table II-3 The satellite fixes between Honolulu to Hilo through the survey area.

Day	A	M	N	R
244	17	6	0	23
245	9	5	8	22
246	14	4	6	24
247	9	2	8	19
248	9	9	7	25
249	5	13	10	28
250	10	5	6	21
251	6	6	8	20
252	7	10	7	24
253*	2	6	3	11
254*	8	3	7	18
255	8	7	7	22
256	13	2	4	19
257	14	2	9	25
258	11	3	5	19
259*	7	0	2	9

	A	M	N	R
Total	132	74	85	291
Average	10.15	5.69	6.54	22.38
Percentage	45.4	25.4	29.2	100%

Remark: data of 253 day and 254 day are not used for statistics because the computer was used for other purposes. Data of 259 day are not used because of arrived Hilo Harbor.

to Hilo for 13 days except during some days when the computer was used for processing. Table II-3 shows these satellite fix number. The average receiving of satellites was 22.4 times per day and 1 h 04 m interval. Auto-update is 10.2 times and 45.5%, Manual-update is 5.7 times and 25.4% and No-update is 6.5 times and 29.2%. Compared with previous statistics, the receiving times decreased 9%, A-update times decreased 28% and the percentage decreased 11%. The decrease of receiving times was probably caused at lower latitudes, that is, the latitude between Chiba to Honolulu is 35N to 21N and the latitude of the center of survey area is 8N. As NNSS satellites go around both the North and South poles, the receiving frequency decreases at the low latitudes. On the other hand the percentage of A-update decrease. Probably this was accidental.

Examinations on the errors of dead reckoning

The errors of the dead reckoning were checked to compare with the satellite fixes. The error σ_s of the satellite fix is usually 200 feet in optimum conditions preparing that the doppler sonar is in the bottom lock mode and the periferal equipment is normal. But the satellite data has some error. The control center injects the new orbit data every 12 hours to the NNSS satellite. After new injection the error σ_s is proportional to passed time t_p and 12 hours make 50 feet errors more. Then

$$\sigma_s(\text{feet}) = 200 + 50\ t_p/12$$

Because the EM-log was used for the speed sensor to water (not to bottom), the errors may be larger.

The error σ_{DR} of the dead reckoning is

$$\sigma_{DR} = \sigma_u + 0.005\ D_{BL} + 0.1\ D_{wT}$$

Table II-4 Satellite fix date examples (Date: 229[d] 1974).

Time	PT	LAT (N)	LON (E)	FIX	ITER	ELEV	FREQ	SAT No.	ALONG	CROSS	RADIAL
h w	h w										
01 38	—	33–45.650	157–19.392	N	10	4.5	21.6	30199	−1.108	2.231	2.491
02 32	2 44	33–45.172	157–32.724	A	3	44	26.3	30130	−1.132	3.211	3.404
02 52	20	33–45.024	157–36.987	A	3	25	27.4	30140	−0.571	0.198	0.604
03 30	38	33–44.574	157–45.816	A	3	26	26.2	30120	−0.193	−0.064	0.203
04 34	1 04	33–43.679	158–00.933	A	3	39	26.4	30140	−0.154	−0.030	0.157
05 16	42	33–42.678	158–10.942	A	3	39	26.0	30120	0.010	0.441	0.441
07 24	2 08	33–38.789	158–39.263	A	3	29	27.4	30190	0.363	1.944	1.977
08 16	52	33–36.447	158–54.761	M	5	9.1	25.2	30180	0.203	0.592	0.625
09 00	44	33–35.302	159–05.905	A	3	29	27.2	30190	0.039	−0.668	0.669
10 00	—	33–34.692	159–19.561	N	3	80	26.3	30180	−1.493	−0.425	1.552
10 56	1 56	33–34.769	159–34.714	M	3	66	26.6	30199	−0.864	−1.156	1.443
11 50	54	33–36.149	159–47.711	M	3	12	26.7	30180	−0.638	−1.548	1.674
12 44	—	32–10.490	156–20.308	N	5	20	899.0	30130	−182.3	90.0	203.3
14 28	2 38	33–38.159	160–25.026	M	3	38	26.5	30130	−0.095	2.164	2.166
14 48	—	33–38.307	160–30.820	N	5	28	27.3	30140	0.916	0.414	1.005
15 24	56	33–37.778	160–39.254	A	3	31	26.5	30130	0.973	1.369	1.680
16 30	1 06	33–37.730	160–55.070	A	3	37	26.6	30140	−0.496	−0.326	0.594
17 08.	38	33–38.143	161–04.158	A	3	34	26.9	30120	−0.530	−0.910	1.053
18 28	1 20	33–38.471	161–23.591	A	3	17	26.9	30190	−0.119	−0.317	0.339
20 14	1 46	33–39.714	161–48.923	A	3	60	27.5	30190	−0.034	−1.279	1.280
21 00	—	33–39.520	161–59.943	N	10	7.9	25.3	30199	0.144	−0.672	0.687
21 18	1 04	33–39.483	162–04.434	A	3	46	26.9	30180	0.341	−0.956	1.015
23 56	2 38	33–34.617	162–37.650	M	3	14	26.9	30130	1.953	4.417	4.830

(Remark for Table 4)
Time 1974y 229d (17th August) crossing Shatzky Rise
TIME: GMT (Greenwich Mean Time) for Satellite Fix
PT: passed time from the last Satellite Fix
LAT: Latitude
LON: Longitude
FIX: Update type, A: Auto-Update
M: Manual-Update
N: No-Update

ITER: Iteration of convergence of calculation
ELEV: Elevation of Satellite at the highest pass
FREQ: Frequency fluctuation of time base
SAT No.: Satellite Number
ALONG: Error of S-Update for Along-course in NM
CROSS: Error of S-Update for Cross-course in NM
RADIAL: Absolute value of error of S-Update
Rms of Along error is 0.684 NM, rms of cross is 1.642 NM and rms of Radial is 1.779 NM in rms of PT 92.07 min for 18 update Sat fixes.

where σ_u is the error of the previous satellite fix, D_{BL} is the cruising distance under the bottom lock mode of the doppler sonar and D_{WT} is one under the water track mode. D_{BL} makes 0.5% error of distance, but on this cruise it was not applied. D_{WT} makes 10% error.

The actual data on this cruise are compared with the proposed error equation. On the printer output the difference of the sat fix to dead reckoning is shown as S-UPDATE, where ALONG stands for the along error and its positive sign is taken when the sat fix proceeds the dead reckoning position along the course, CROSS stands for the cross error, the starboard side being positive and, RADIAL is the absolute value in the units of nautical miles.

Table II-4 is the sat fix data of the 229 day, 17th August. The Hakurei-Maru cruised across the Shatzky Rise on this day, and the average speed was 11.9 knots towing the

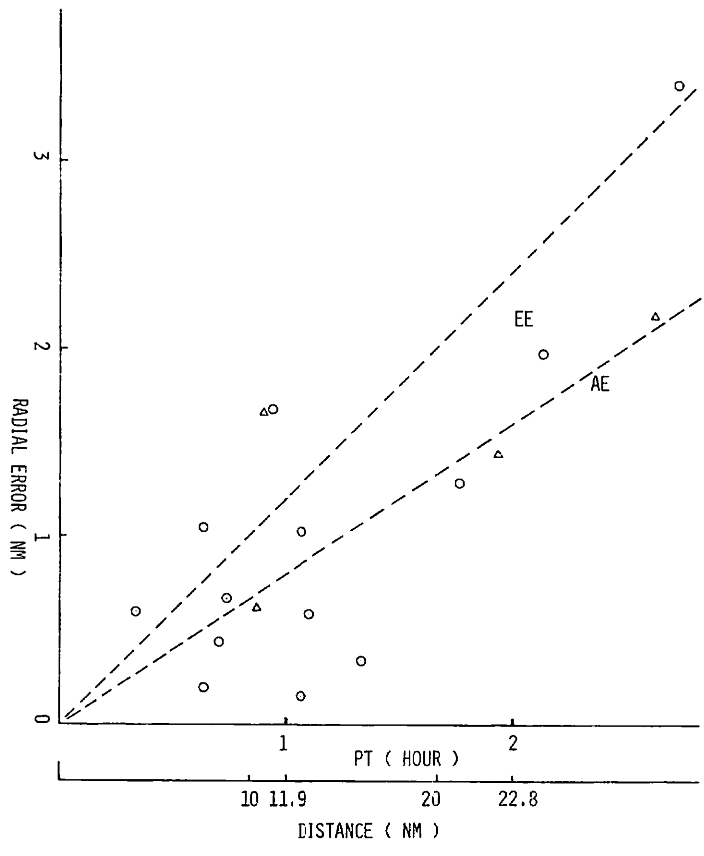

Fig. II-2 Radial error of the dead reckoning.
The radial errors of 18 sat fixes on 229 day are plotted versus distance. x-axis is both the passed time from the last sat fix and distance by the average speed 11.9 knots towing the airgun. y-axis is the radial error in nautical mile. The open circles are auto-update and the triangles are manual-update. On this figure one of sat fix data is omitted, which is fix time 23 h 56 m, PT 2 h 38 m and radial error 4.83 NM.
AE is the average and the radial error is 6.5% of distance. EE is the estimated error 10% by the maker.

airgun holding 90 degree east-ward. The reason for the choice of the 229 day is that the speed and direction were kept constant all day. The data presented are reasonable except for the 12 h 44 m sat fix. In this sat fix the frequency fluctuation is 899 Hz with the average frequency of 27 Hz through more than 30 times, and the radial error is 203 NM and extremely large. It is caused by the message change by the satellite transmitting. This is no-update.

Fig. II-2 shows the relation of the passed time PT from the last sat fix versus the radial error. The distances are calculated, assuming an average speed of 11.9 knots. The relation is not always linear but generally speaking the radial errors increase with passed time PT. AE is the average error which is

$$\text{error(NM)} = 0.065\ \text{D(NM)}.$$

This error of 6.5 percent is smaller than the estimated error EE 10 percent by the maker. If the 10 percent error is adopted, 66 percent data are smaller than the EE line. Then a 10 percent error for the dead reckoning is reasonable.

The radial error and the cross error were compared to each other. In Fig. II-3, the x-axis is the along error in nautical mile and the y-axis is the cross error. If the research vessel is on the origin at the sat fix instant, the ship runs along the y-axis downward. The Rms (root mean square) of along error for 18 sat fixes is 0.684NM and rms of cross error is 1.642NM, so rms of radial error is 1.779NM. Rms of passed time is 91.07 minutes and its distance is 18.0NM at 11.9 knots. Therefore, the along error is 3.8 percent of the distance, cross error is 9.1 percent and radial error is 9.1 percent and radial error is 9.8 percent.

Concerning to the Hakurei-Maru's navigational system, the rms of cross error are

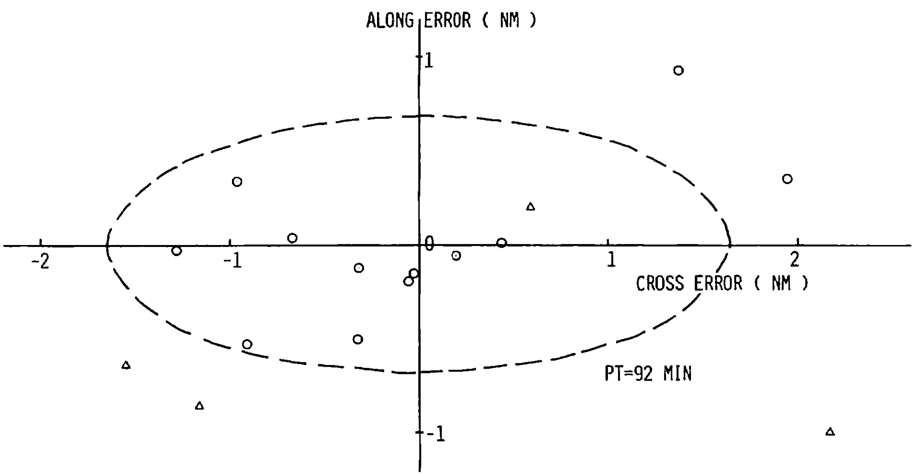

Fig. II-3 Error and cross error of the dead reckoning. x-axis is the cross error of the dead reckoning for the sat fix in nautical mile and the starboard side is positive. y-axis is the along error and the running direction is negative. Then the boat is on the origin at the sat fix instant running along y-axis downward. Two sat fixes data of 02 h 32 m, along error −1.132 NM, cross error 3.211 NM and 23 h 56 m, along error 1.953, cross error 4.417 are omitted on this figure but used for rms. Rms of along error of 18 sat fixes is 0.68 NM and rms of cross error is 1.64 NM which is 2.4 times, and rms of passed time is 92.1 min. Rms values make the error region as the ellipse.

2.4 times of that of the along error. Along error is caused mainly by the EM-log and the cross error is caused by the gyro-compass. As the error affected by the gyro-compass is 2.4 times, the error region of the dead reckoning is not a circle but an ellipse elongated in the direction of cruising. The ellipse on the figure is the error ellipse at 1 h 31 m of passed time.

Summary

NNSS was mainly used in the present cruise, and particularly two technical problems on the field status of the satellite fixes and the errors of the dead reckoning were examined on board. The average of 11 days between Chiba to Honolulu was that the satellite waves were received 24.7 times per day and 14.0 times among them were auto-update, and 3.73 times in no-update sat fixes were manually updated. The average time interval of auto-update is 1 h 43 min, but the maximum interval of the 229th day in Table II-4 was 6 h 24 min. The average interval of both auto- and manual-update was 1 h 21 min.

During this cruise, the sea was deep and the ship velocity was detected by non-bottom-lock way. Analyses were given to the error of the dead reckoning in non-bottom-lock speed compared with S-update of sat fix computation. The system maker indicates that the dead reckoning error is about 10 percent of running distance. The averaged error in this cruise, however, was a little smaller than the proposed error of the system maker, so a 10 percent error is considered to be reasonable.

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