MIR ORBIT DETERMINATION USING OPTICAL OBSERVATIONS AT BISEI SPACEGUARD CENTER

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ABSTRACT

The MIR re-entry brought much concern to Japanese government and public, because its final orbit had been announced to pass over Japanese populated area. We have carried out optical observations of the MIR space station from January 15 to March 11, 2001, when the MIR was visible from our observatory site and obtained enough accurate data for each observation night to determine its orbit. However, our observational capability is limited. It is necessary to develop a more accurate system and an idea is proposed. Using our data and NASA's two-line elements we were able to determine the MIR final re-entry pass with sufficient accuracy and gave these information to the public through mass-media.

1. INTRODUCTION

There was much concern on the MIR re-entry event in Japan since its final orbit had been announced to pass over Japanese populated area. However, there were no facilities in Japan to observe its positions for orbit determination.

We are now developing a radar system which can detect simultaneously ten objects with a diameter below 1.0m at 500km altitude. It will become operational in 2004 (Tajima et al., 2001). We are also developing an optical observatory for detection of Near Earth Asteroids (NEAs) and space debris with three telescopes with apertures of 1.0m, 50cm, and 25cm. The telescopes with 50cm and 25cm apertures are now operational. The telescopes have a wide field of view of 2° in diameter and a high tracking motion of 5° per second. The angular motion of the MIR was very fast. We did not have enough accurate positions derived from NASA's two-line elements (TLE).

After finding this difficulty we produced a new system in a few weeks and applied it to the MIR observations. As shown in this paper, we could make successful observations and its orbital determination, although our observations were limited to a period when it was dark at the observation site and the MIR station was in sun light.

Here, we will show our method of the MIR observations and its orbit determination. We could give good information to our concerned Japanese public. Finally, a new idea is presented to increase the position accuracy.

2. THE BISEI SPACEGUARD CENTER AND ITS OPTICAL SYSTEM

After a two year lobbying activity of the Japan Spaceguard Association (JSGA), we succeeded to get the budgetary support for a NEA detection observation from the Science and Technology Agency. The Japan Space Forum (JSF) was charged to build the Bisei Spaceguard Center (BSGC), which contains three telescopes with apertures of 1.0m, 50cm, and 25cm designed by one of the authors (Isobe 2000a, 2000b, 2001).

The JSF owns the Center and the telescopes. The Japan Spaceguard Association is operating the Center with financial support of the National Space Development Agency (NASDA), which has been requesting the BSGC to observe optically in an experimental mode a number of space debris objects and some satellites.

Five JSGA observing staff are available for NEA and space debris observations during 365 nights per year. When NASDA requested the MIR observations using existing system at the BSGC in January, the observations with the 25cm telescope failed because its positions computed from the TLEs were different from the real positions by about 10°.

Immediately, we decided to build an optical system with a much wider field of view using parts available at

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the BSGC. Table 1 shows two systems used at the first and last half periods. In the beginning we had long streak images depending on the exposure time and these measured positions were inaccurate. Then, following a paper by Isobe (1997) we introduced a chopping system, which generated gaps on each streak.

Table 1. Some characteristic numbers for two systems used for the MIR observations.

		Observation Instruments	
		Jan. 27 – Feb. 13	Feb. 14 – Mar. 9
Lens	f	150 mm	165 mm
	f-ratio	2.8	2.8
	d	54 mm	58 mm
	–	10.9 degree	9.9 degree
CCD		Apogee 10	Apogee 10
	pixel	2k x 2k	2k x 2k
		19.3 arcsec/pixel	17.5 arcsec/pixel
Exposure time		15 seconds	15 seconds
Chopping shutter		1 second/chop	1 second/chop
Limiting magnitude		12 magnitude	12 magnitude

The complete system (Fig.1) was developed by the Bisei staff in a short time. Obviously, with more time available for the design of the system, there is a high probability to have a much better system for re-entry observations of space debris.

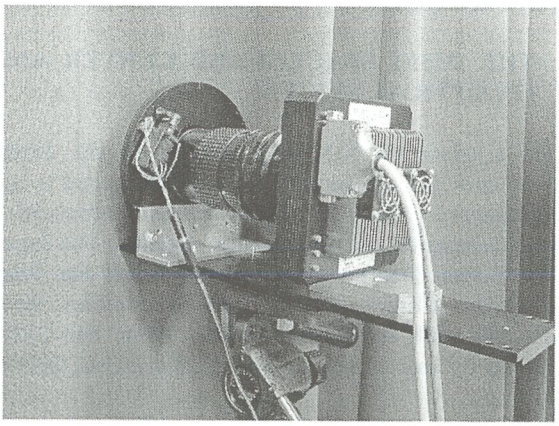

Fig. 1. View of the MIR detection and observation system. It comprises a chopper, a camera lens, and a CCD camera.

3. MIR OBSERVATIONS AND INTERNAL ACCURACY

We made observation as shown in Table 2. Fig. 2 and 3 are examples obtained on January 27 and February 13 with and without the chopping system. It is clear that observations with the chopping system are more accurate than those without. Positions of the MIR at different streak images in each frame are obtained using star positions. Table 3 shows internal errors of positions for reference stars. The least mean square values in right ascension and declination are 2.00 and 1.66 arc seconds, which are reasonable values for a point source with a CCD pixel size of around 20 arc second. However, since the MIR images are streaks, the accuracy of the position determination is much worse than indicated by the above values.

Table 2. A list of the MIR observations carried out by our team.

Month	Jan.	Feb.	Mar.
Observed Day	1/14 1/27 1/28 1/29 1/30	2/13 2/14 2/16 2/22 (kashima) 2/25 (gekko) 2/26 (kashima) 2/27 (kashima)	3/9 3/9 (kashima) 3/10 (kashima) 3/11 (kashima) 3/13 (kashima)

Fig. 2. An image without a chopping system January 27, 2001. An image with a long streak shown with many point-like background stars.

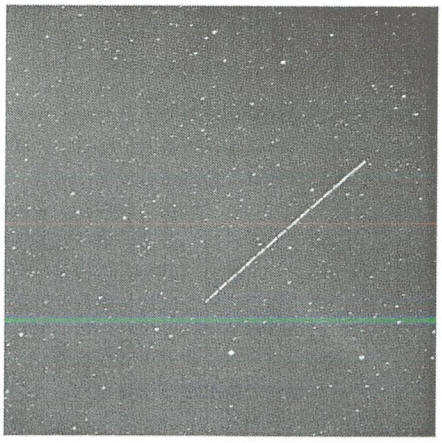

Figure 3. An image with a chopping system on February 13. A broken line is shown with many point-like background stars.

During early January when we tried to observe MIR at positions predicted by the TLE, MIR had a delay of several ten seconds in time. Therefore, we could not detect it. Using our new hand-made system, we watched it by a binocular and brought it in the field of view of our camera.

4. ORBIT DETERMINATION

During our observation period, the altitude of the MIR orbit was decreasing because of air-drag. Therefore, we could not link all the observed data in a single data set. Assuming that the MIR kept its orbital elements within a certain period (1 day to 3 days) we tried to obtain its orbital elements using each data set. Table 3 shows O-C value for the observations of February 13 and 14, where each C value is obtained from orbital elements determined by all the observed values. These O-C values are far larger than the internal stellar position error of an order of 1 arc second for each data set, because of effects of air-drag. Table 4 shows the root mean square values of each component for each observed point.

Table 3. O-C values for a data set of February 13 and 14, 2001.

Object	Date/UT	R.A.(2000) h m s	Decl. ° ′ ″	***O-C*** ″ ″	Code/Obs
MIR	2001 02 13.844803	22 25 43.16	+52 18 36.4	55.5+28.9+	300/SG
MIR	2001 02 13.844815	22 23 52.48	+51 57 12.5	67.9+40.8+	300/SG
MIR	2001 02 13.844826	22 22 07.09	+51 36 45.8	26.5+ 8.3-	300/SG
MIR	2001 02 13.844838	22 20 19.62	+51 15 34.0	33.3+45.4+	300/SG
MIR	2001 02 13.844861	22 16 54.80	+50 32 57.1	6.0- 14.7+	300/SG
MIR	2001 02 13.844873	22 15 05.18	+50 10 09.5	61.5- 26.6-	300/SG
MIR	2001 02 13.844884	22 13 27.71	+49 49 16.3	(0.03- 0.02-)	300/SG R
MIR	2001 02 14.847176	20 18 36.95	+23 17 20.6	20.8+60.4-	300/SG
MIR	2001 02 14.847188	20 18 13.09	+22 50 12.2	47.2+61.1+	300/SG
MIR	2001 02 14.847199	20 17 48.83	+22 21 45.7	30.9+57.1-	300/SG
MIR	2001 02 14.847211	20 17 25.42	+21 53 34.0	47.6+33.3-	300/SG
MIR	2001 02 14.847222	20 16 57.78	+21 24 18.1	(0.01- 0.06-)	300/SG R
MIR	2001 02 14.847234	20 16 33.27	+20 56 40.5	(0.01- 0.06-)	300/SG R
MIR	2001 02 14.847245	20 16 12.38	+20 31 59.0	(0.01- 0.05-)	300/SG R
MIR	2001 02 14.847257	20 15 50.31	+20 06 48.9	37.1- 26.7-	300/SG
MIR	2001 02 14.847280	20 15 08.32	+19 16 38.0	43.1- 71.4+	300/SG
MIR	2001 02 14.847292	20 14 46.58	+18 49 51.1	54.3- 61.2+	300/SG
MIR	2001 02 14.847303	20 14 25.01	+18 23 06.4	94.1- 94.8-	300/SG
MIR	2001 02 14.847315	20 14 05.00	+17 58 34.2	94.0- 3.0-	300/SG
MIR	2001 02 14.847326	20 13 45.13	+17 34 04.2	(0.03- 0.02-)	300/SG R
MIR	2001 02 14.847593	20 08 22.96	+09 08 30.7	84.4+13.7-	300/SG
MIR	2001 02 14.847604	20 08 12.30	+08 50 00.4	81.4+26.4-	300/SG
MIR	2001 02 14.847616	20 08 00.28	+08 31 01.8	68.4+19.9+	300/SG
MIR	2001 02 14.847627	20 07 48.00	+08 12 27.6	34.4+19.7-	300/SG
MIR	2001 02 14.847639	20 07 38.86	+07 52 58.7	56.8+28.5-	300/SG
MIR	2001 02 14.847662	20 07 15.93	+07 17 22.5	8.9- 23.6+	300/SG
MIR	2001 02 14.847674	20 07 07.25	+06 58 33.2	27.4+17.9+	300/SG
MIR	2001 02 14.847685	20 06 55.22	+06 41 03.5	19.3- 12.5-	300/SG
MIR	2001 02 14.847697	20 06 46.04	+06 23 03.9	15.0- 8.2-	300/SG
MIR	2001 02 14.847708	20 06 35.94	+06 05 15.2	39.1- 62.2-	300/SG
MIR	2001 02 14.847720	20 06 27.38	+05 48 57.9	31.9- 38.1+	300/SG
MIR	2001 02 14.847731	20 06 17.99	+05 31 24.9	51.3- 37.1-	300/SG
MIR	2001 02 14.847743	20 06 08.78	+05 14 55.2	60.0- 28.8+	300/SG

Table 4. The root-mean square values of each component estimated for each observed period.

	Using Data (Data Num.)	_R between TLE and NASDA O. D. (km)	O – C RMS	
			Az (arcsec)	El (arcsec)
Case 1	Bisei 1/29, 30 (38)	90.6	141	95
Case 2	Bisei 2/13, 14 (33)	2.7	67	50
Case 3	Kashima 2/26, 27 (15)	44.3	246	20
Case 4	Bisei 2/25 (16) Kashima 2/26, 27 (15)	4.9	177	21
Case 5	Kashima 3/9,10,11(14)	9.6	27	34

5. RE-ENTRY ESTIMATION

Using the software developed for a calculation shown in section 4, the MIR orbit after its final maneuvering was estimated in order to respond to a severe concern of the Japanese government and the public. Fig. 4 shows its path over Japan and Fig. 5 shows its altitude as function of time after crossing the point No.3 in Fig. 4. After distributing this figure through mass-media, the anxiety of the public had vanished.

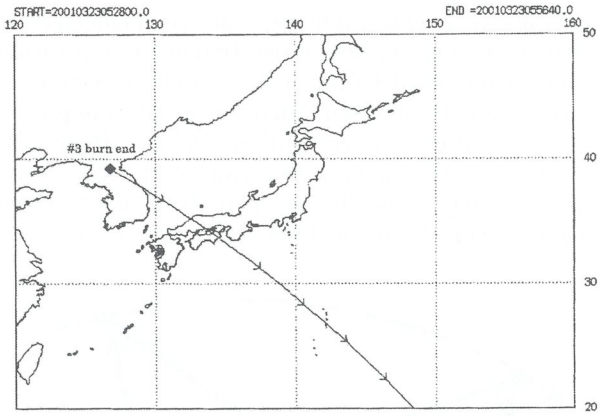

Fig. 4. The MIR pass after the final maneuvres.

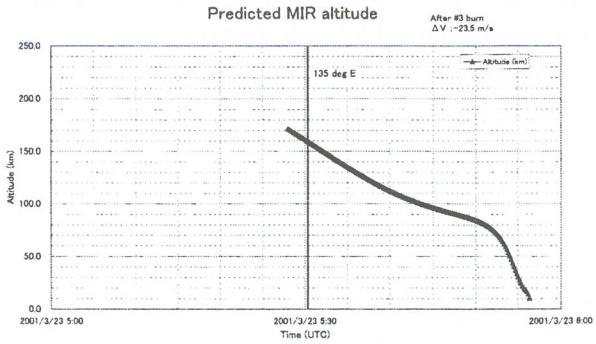

Fig. 5. The MIR altitude as function of time after the final maneuvres.

6. CONCLUSION

Since we had no instrument to determine orbital elements of the MIR, we quickly developed a new ad-hoc optical observing system which could produce accurate positions at different times. Fortunately, there were many clear nights when the MIR could be seen illuminated by the sun. Considering this constraint, radar observations could be more powerful to determine its orbital elements.

There is an idea to obtain highly accurate optical observations for the re-entry of space debris. Since optical observation determines a projected position of an object on the celestial sphere and radar observation determines only its distance, we can not get the three-dimensional position from a single observation. If we can observe an object from two sites simultaneously as shown in Fig. 6, all three-dimensional position components are determined by a single observation. Assuming 0.01° of observational error one can predict an error after one revolution. While single site observations give about a 10° error, observations from two sites may reduce the error to about 0.5° which depends on the longitude difference of the two sites.

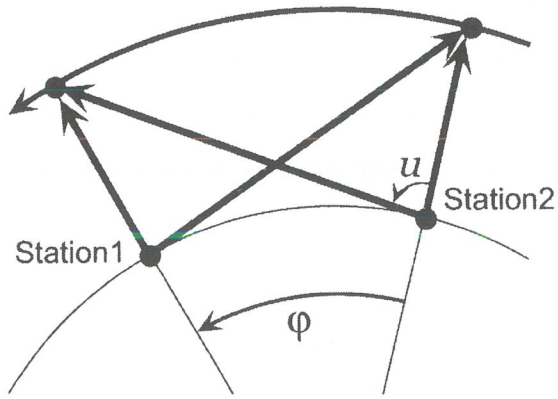

Fig. 6. A schematic view of a trigonometric observation with two observational sites is shown.

In conclusion, we could get good data from optical observation and show a possibility to obtain highly accurate data using simultaneous observations from two sites.

7. REFERENCES

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