Evaluation of DGPS Positioning in Urban Area Using MF Radio Beacon and FM Sub-Carrier Broadcasting

Journal of Tokyo University of Fisheries, Vol. 86, No. 2, pp. 11–24, December 1999

Evaluation of DGPS Positioning in Urban Area Using MF Radio Beacon and FM Sub-carrier Broadcasting*

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In the SPS (Standard Positioning Service) of GPS, the positioning accuracy is degraded intentionally to about 100 m by for example SA (Selective Availability) error. However, GPS accuracy can be improved to less than 10 m by using Differential GPS (DGPS) of the pseudo renege correction type. In Japan, for civil land use, we can utilize two types of major DGPS services. One uses the maritime MF radio beacon operated by the Maritime Safety Agency, and the other the FM sub-carrier broadcast offered by Satellite Positioning Information Center Ltd.. However the differential correction data format and the data transmission rate of these two DGPS services are quite different, which is expected to affect the positioning accuracy the different systems.

The fixed-point observations were carried out for verification at an urban area in Tokyo, and the characteristic of both systems and the difference in their DGPS positioning accuracy were compared to evaluate the current receiving situation. From the results, it was found that the positioning accuracy of the MF-DGPS was higher than that of the FM-DGPS because of its high data transmission rate. The actual receiving characteristics of each DGPS were also clarified this study. In this paper, we describe the evaluation results and suggest future effective uses.

Key words: GPS (Global Positioning System), differential GPS (DGPS), maritime MF radio beacon, FM sub-carrier broadcast, positioning accuracy

Introduction

GPS (Global Positioning System), a satellite-based radio navigation system managed by the USA, provides its SPS (Standard Positioning Service) for civil use. GPS user's equipment performs a range of measurements among the individual satellite and the user and to determine his/her position. However, the SPS has 100 m horizontal positioning accuracy due to various errors such as SA (Selective Availability), tropospheric delays, unmodeled ionosphere delays and others[1),2)].

Differential GPS (DGPS) is a system in which the accuracy of GPS is enhanced less than 10 m with high reliability. In Japan, we can utilize two types of DGPS services roughly classified.

* Received May 11, 1999.

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One uses the maritime Medium Frequency (MF) radio beacon mainly for marine navigation and the other uses Frequency Modulation (FM) sub-carrier broadcast for car navigation mainly. However, the two systems, have different differential correction data formats[3].

In this study, the positioning accuracy of the two DGPS systems for an urban area were evaluated by actual surveys and compared for the purpose of clarifying their appropriate uses.

Architecture of DGPS

Differential corrections may be used in real-time corrections or post-processing techniques. However, real-time corrections can be used in navigation to know the current position instead of the post-processing techniques. Accordingly, DGPS generally shows real-time corrections.

Real-time correction data may be transmitted to the user continuously by radio link. A reference GPS receiver, located at an exactly defined position, indicates the true distance among the position and GPS satellites and the calculated differential correction of the GPS signal. These calculated errors are processed as differential correction data, and then sent through the data transmission station. The user's DGPS receiver corrects the measured distance (pseudo-range) between the user and the GPS satellites using the differential correction data.

The corrected pseudo range PR(t) can be expressed as

$$PR(t) = PRM(t) + PRC(t_0) + RRC(t_0) \cdot (t - t_0) \quad (1)$$

where PRM(t) : the pseudo range measured by the user at time t

$PRC(t_0)$: correction value of the pseudo range at time t_0 at the reference

$RRC(t_0)$: variation rate of $PRC(t_0)$.

The equation shows that the corrected pseudo range depends on PRC, RRC and the delay time $(t - t_0)$. Hence, the differential correction data transmitted from the reference station are composed of PRC, RRC and t_0. The concept of the two DGPS service systems and the observation results of using the maritime MF radio beacon and the FM sub-carrier broadcast are described as follows. Table 1 shows the specifications for each DGPS service.

Materials and Methods

Maritime MF Radio Beacon DGPS (MF-DGPS)

Using the maritime radio beacon signal (carrier wave frequency about 300 kHz), DGPS corrections are reliably transmitted in standard format specified by the RTCM SC104 (Radio Tech-

Table 1. DGPS service specifications

Type of DGPS service	Maritime MF radio beacon	FM sub-carrier broadcasting
Coverage area	Sea within 200 km radius form DGPS site	Within about 30 km radius from FM broadcasting station
Transmission format	ITU-R M.823-1(RTCM SC-104)	DARC
Update interval	About 3 seconds	About 5 seconds

nical Commission for Marine Services, Special Committee No. 104). The differential correction data update interval is about 3 seconds. This system is based on international standards.

JMSA (Japan Maritime Safety Agency) is improving the existing maritime MF radio beacon stations as DGPS sites for marine navigation. This system officially began operation in Feb. 1996 and should be able to provide its service in all coastal waters around Japan by the end of March 1999. This system is constituted of a total of 27 sites (reference and broadcasting stations) and one control station (Fig. 1).

In the Kanto region, MF radio beacon stations are located at Turugi Saki, Inubo Saki and Hatizyo Sima. I was determined the DGPS positioning accuracy using these three beacon stations.

A GPS antenna (NovAtel GPS-501) which has a multi-path resist chalk ring (NovAtel model A 031) was set on the roof of the Marine Science and Technology building in Tokyo University of Fisheries. Two GPS receivers (NovAtel 3151R) were connected to the antenna distributor. One was used for DGPS positioning with correction data from the Turugi Saki maritime radio beacon station. The other was used for DGPS position measurement with correction data from Inubõ Saki or Hatizyõ Sima (Fig. 2).

On July 1 in 1998, observation was made for 24 hours continuously with the signal received from Turugi Saki and Hatizyõ Sima. On August 12 in 1998, a similar observation was made for 24 hours using signals from Turugi Saki and Inubõ Saki.

The data were collected of the NMEA (National Marine Electronics Association) GPGGA (Global Position System Fix Data) data at every 15 seconds, and were recorded on a personal computer (Toshiba Dynabook 300CDS). Then, the MF radio beacon signal strength (SS) and signal-to-noise ratio (SNR) indicated by the MF radio beacon receiver were simultaneously recorded every 30 minutes by manual operation. These values are not absolute but relative for the MF receiver. The elevation cut-off angle, below which GPS satellites are unavailable for positioning, was set at 10 degrees above the horizon in order to avoid the reduction of positioning accuracy.

FM Sub-carrier Broadcasting DGPS (FM-DGPS)

This system service has being provided by GPex (Satellite Positioning Information Center Ltd.)[4] since May 1997 mainly for car navigation. The FM sub-carrier transmits the FM-DGPS service of DARC (Data Radio Channel)-type data. This system has 7 reference stations and 37 FM broadcasting stations (Fig. 3). The update time for differential correction data is about 5 seconds in this system.

The GPS receivers used in the survey measure RTCM data for DGPS positioning. Accordingly, data in the DARC format received by the FM sub-carrier receiver were converted into the RTCM format for DGPS positioning. Time data are not included in the DARC data; therefore time information from an outside source or the FM sub-carrier broadcasting time is needed. Since the

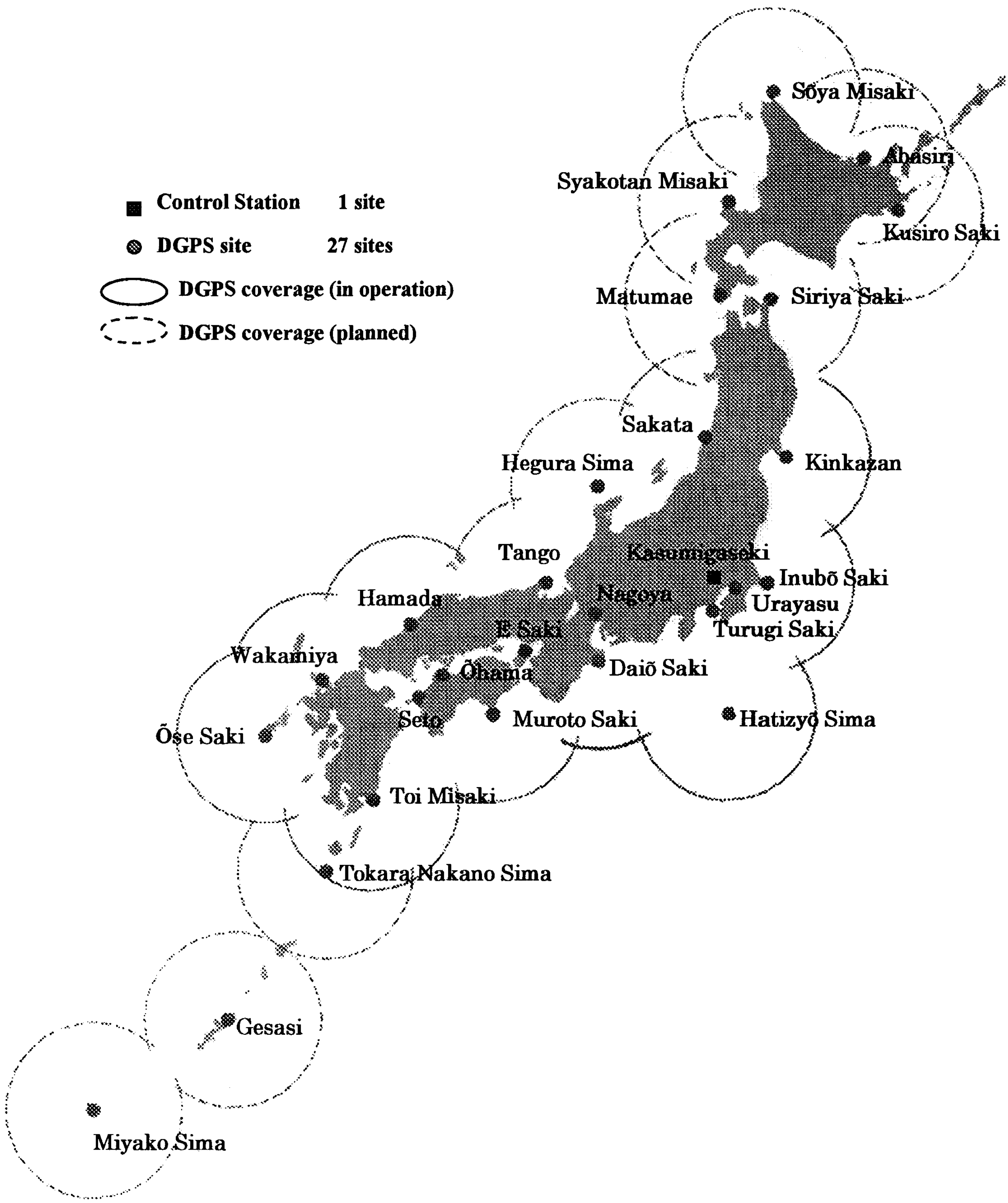


Fig. 1. JMSA's maritime DGPS sites and coverage

method at utilizing time information from FM sub-carrier broadcasting is the same as that used in general car navigation, it was selected in this observation.

The GPS receiver was set in a car and position measurement in the vicinity of the center of Tokyo was made, and the position precision was evaluated. A GPS antenna (NovAtel Model

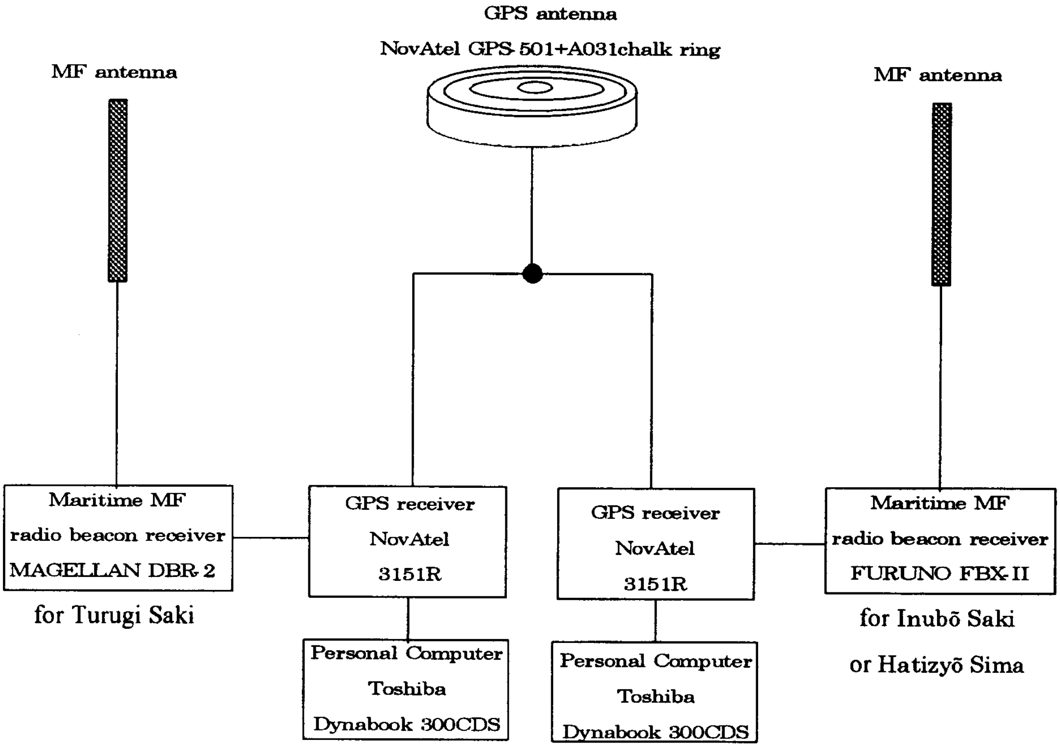


Fig. 2. Schematic diagram showing the observation equipment for MF-DGPS.

521), GPS receiver (NovAtel 3151R), FM antenna (Autobacs Seven: LR-25), FM sub-carrier broadcasting receiver (Data Tec M51-001) and personal computer (Toshiba Dynabook 300CDS) were used for the observation (Fig. 4).

Eight cardinal and inter-cardinal points about 10 km from Tokyo Tower, which transmits FM multiplex broadcasts, was chosen for the observation sites. Continuous observation was made for one hour at each observation point (Fig. 5). The data were collected in an NMEA GPGGA log for every 1s on the personal computer, and the elevation cut-off angle was set at 10 degrees above the horizon.

Simultaneous Observation by MF and FM-DGPS

A GPS antenna (NovAtel GPS-501) which had a multi-path resist chalk ring (NovAtel model A031) was set on the roof of the Marine Science and Technology building in Tokyo University of Fisheries. Two GPS receivers (NovAtel 3151R) were connected to the antenna distributor. One was for DGPS positioning using correction data from the Turugi Saki maritime MF radio beacon station. The other was for DGPS position measurement using correction data from the TOKYO FM broadcast from Tokyo Tower (Fig. 6).

On September 2 in 1998, the observation was came out for 24 hours. Both sets of DGPS data were simultaneously collected in NMEA GPGGA logs for every 15 seconds on personal computers. The elevation cut-off angle was set at 15 degrees above the horizon.

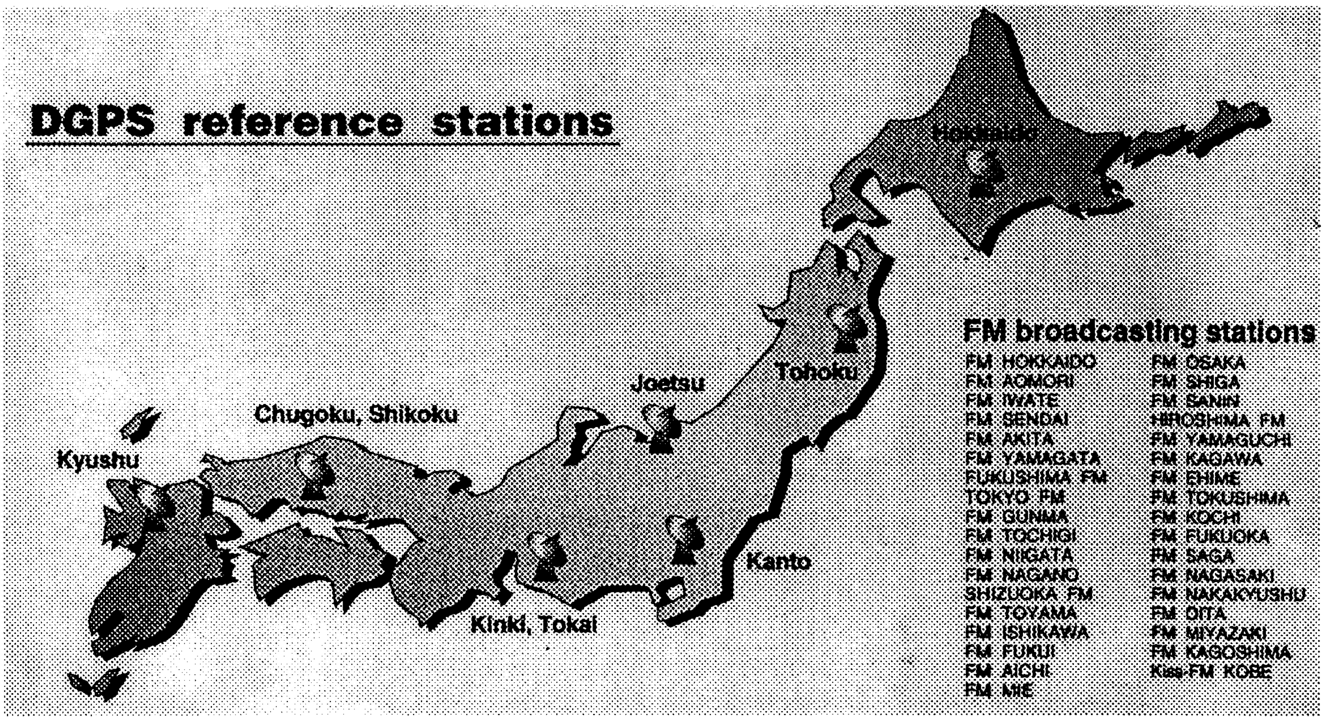


Fig. 3. FM sub-carrier DGPS reference stations and FM broadcasting stations.

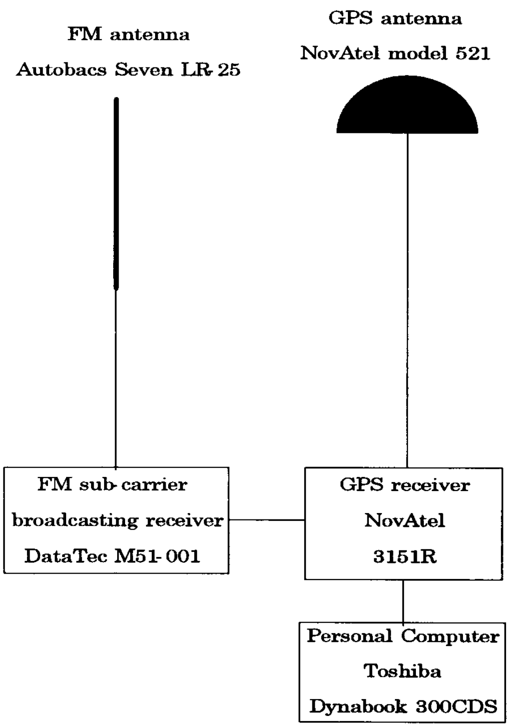


Fig. 4. Schematic diagram showing the observation equipment for FM-DGPS.

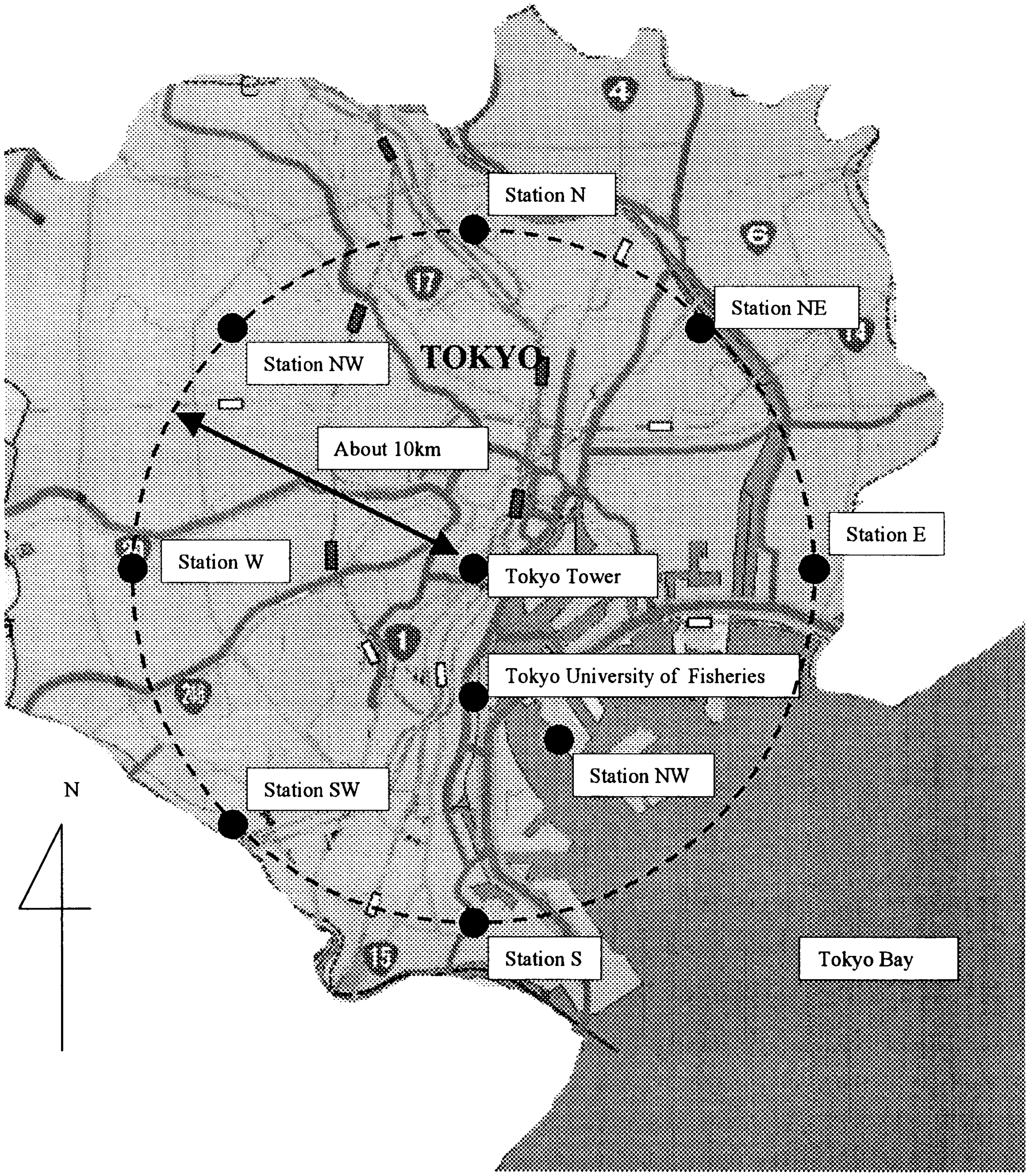


Fig. 5. The observation stations for FM-DGPS around Tokyo Tower.

Results and Discussion

Maritime MF Radio Beacon DGPS (MF-DGPS)

The scatter of position error using the three MF radio beacons is plotted in Fig. 7 a) Turugi

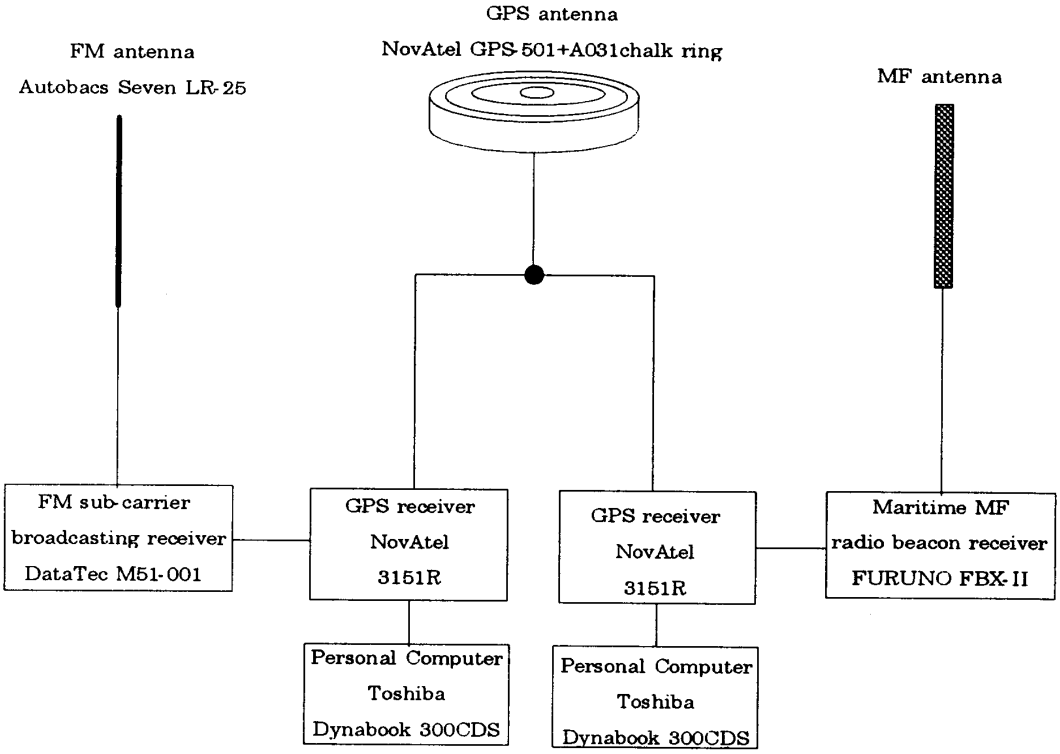


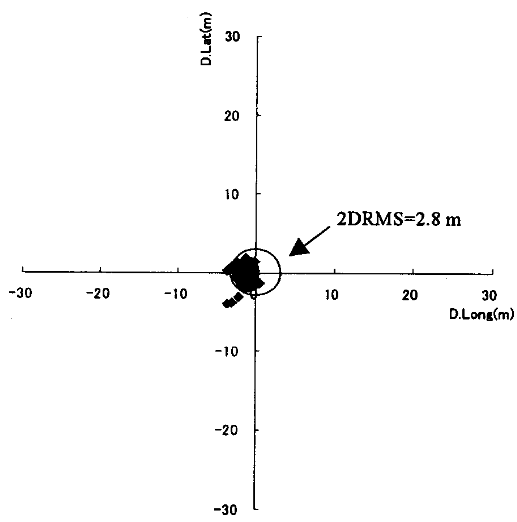
Fig. 6. The observation equipment for MF-DGPS and FM-DGPS

Table 2. DGPS positioning results for Maritime MF radio beacon stations in Kanto region

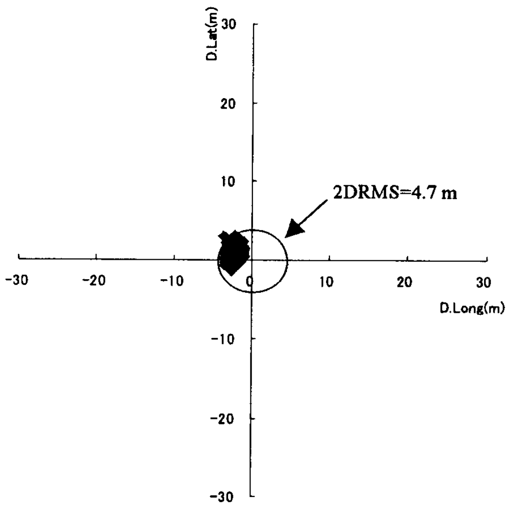
Observation date	1998/6/30 ~ 1998/7/1		1998/8/11 ~ 1998/8/12	
Maritime MF radio beacon site	Turugi Saki	Inubō Saki	Turugi Saki	Hatizyō Sima
Distance of Base line (km)	55	98	55	260
2DRMS (m)	2.8	4.7	2.9	10.7
2σ (m)	1.1	1.2	1.3	9.1
Average latitude error (m)	0.3 S	0.9 N	0.5 S	1.3 N
Average longitude error (m)	1.3 W	2.1 W	1.2 W	2.9 W
Average HDOP	1.19	1.23	1.18	1.26
Number of Average common visible satellites	7.3	7.2	7.3	7.2
Average SS	52.1	56.0	52.0	39.1
Average S/N	24.2	24.2	26.6	10.7

Saki, b) Inubō Saki and c) Hatizyō Sima, and Table 2 shows the results. There were no differences in the number of common visible satellites and average HDOP (Horizontal Dilution of Precision). However, the positioning accuracy using the Hatizyō Sima MF radio beacon is the worst with a 2DRMS (two times distance root mean square: radius of 95 % probability error circle) value of 10.7 m which is worse than the positioning accuracy of 2DRMS = 10 m guaranteed by JMSA. This reason is that the base line (distance from reference site to user) exceeds the 200 km-service area of a MF radio beacon. Therefore, particularly when the SNR becomes low during the night (Fig. 8), reception rate of the message to revision data for the DGPS decreased to 81%.

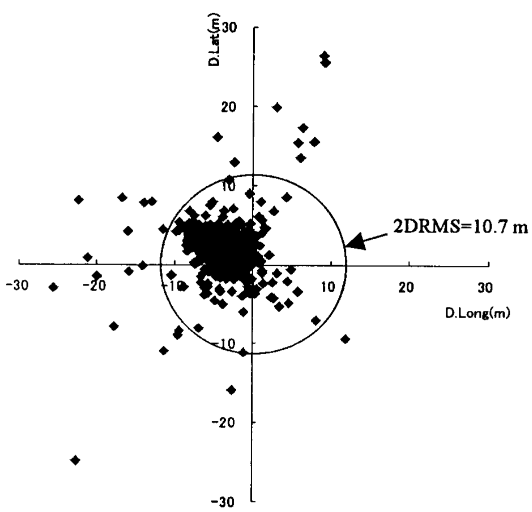
The precision of positioning accuracy was the highest (2DRMS = 2.8 m) when the base line



a) Turugi Saki



b) Inubō Saki



c) Hatizyō Sima

Fig. 7. The scatter plot of position error using maritime MF radio beacons. a) Turugi Saki site, b) Inubo Saki site, c) Hatizyo Sima site.

(55 km) was the shortest, Turugi Saki. This result clearly supports the result reported other papers[5), 6)] that the positioning accuracy deteriorates as the base line becomes longer.

FM Sub-carrier Broadcasting DGPS (FM-DGPS)

In these observations, the average position of observed data was used as the basic position for calculating the positioning error at each observation point because of the difficulty in finding an absolute position. The position error was evaluated by using the value of two times the standard deviation (2 σ) of horizontal radial error.

Two typical results are shown as examples. Station N, there were high buildings in the vicinity, and the DGPS observation rate was low. On the other hand, for Station S, the building of circumference was low and the position precision was higher than for Station N. Consequently, the distributed difference in position error between the two stations was about 5 times disparity (Table 3). The reason is thought to be that the capability of a GPS satellite, which can be utilized, is limited for position crowded buildings and where roads are narrow. However, position precision is even high though the DGPS observation rate is poor, as seen for station NW. When FM sub-carrier broadcasting data are utilized, a strong electric field is necessary, and it seems to be probable that the revision data become irregular even if a usual FM broadcast in stereo. The cause of irregularity, it is thought to be the degradation of the FM sub-carrier broadcasting reception rate.

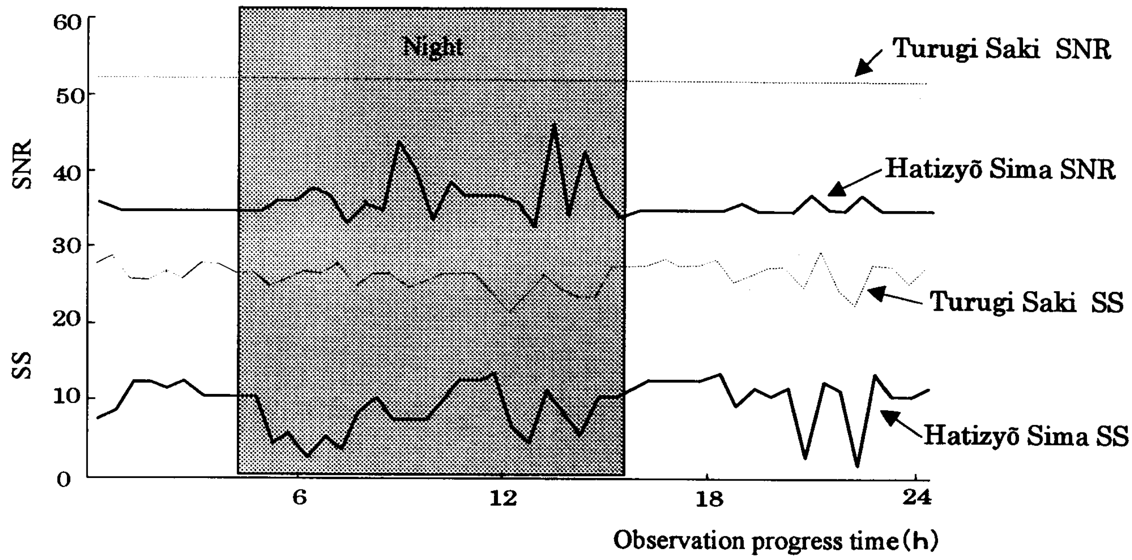


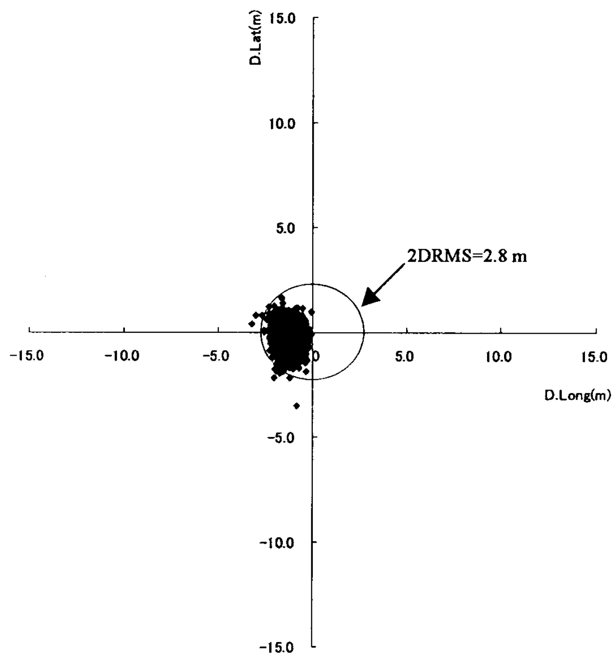
Fig. 8. SNR and SS were compared with Turugi Saki site and Hatizyo Sima site.

Table 3. DGPS positioning accuracy of FM sub-carrier broadcasting

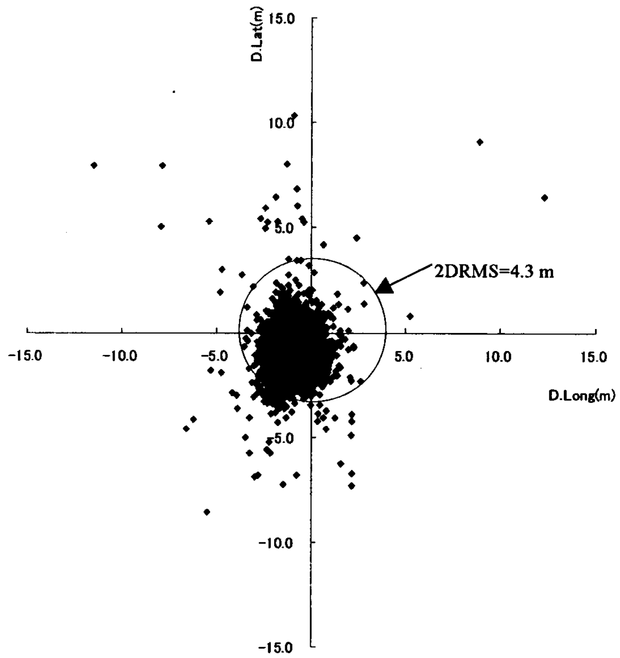
Station Name	N	NE	E	SE	S	SW	W	NW
2σ (m)	42.1	23.8	8.0	5.4	8.1	6.0	35.1	12.2
DGPS observation rate (%)	40.6	100.0	100.0	95.8	100.0	100.0	84.6	42.3

Simultaneous Observation by MF and FM-DGPS

The scatter of position error using the MF radio beacons is plotted in Fig. 9 a) and that using the FM sub-carrier is plotted in Fig. 9 b). There was no difference in the number of common visible satellites or average HDOP, but the positioning accuracy using the MF radio beacon is



a) Maritime MF radio beacon



b) FM sub-carrier broadcasting

Fig. 9. The scatter plots of position error were compared between MF-DGPS and FM-DGPS. a) MF-DGPS from Turugi Saki site and b) FM-DGPS from Tokyo Tower.

Table 4. Comparison of MF-DGPS and FM-DGPS positioning results

DGPS service	Maritime MF radio beacon (Turugi Saki)	FM sub-carrier broadcasting (Tokyo Tower)
2DRMS (m)	2.8	4.3
2σ (m)	1.1	3.6
Average latitude error (m)	0.4 S	0.8 S
Average longitude error (m)	1.2 E	0.8 E
Average HDOP	1.2	1.2
Number of Average common visible satellites	7.3	7.2

better than that using the FM sub-carrier, based on 2DRMS and 2σ (Table 4). The reason for this is that the differential correction data update interval for the FM multiplex is longer than that for the MF beacon. This correction data transmission delay is thought to influence the positioning[7], and furthermore, deterioration of revision information occurs due to the conversion of the DRAC format to the RTCM format.

Conclusion

In this study, the positioning accuracy of two DGPS systems for an urban area was evaluated by actual surveys and compared. First, the influence of a change of base line length on the MF-DGPS positioning accuracy was discussed. The influence of the observation site's environment on the positioning accuracy was investigated for an urban area, using FM-DGPS. Finally, the positioning accuracy for the two different types of DGPS systems were compared at a fixed point.

The results of these observations are shown as follows.

1) The MF-DGPS positioning accuracy deteriorated in proportion to the length of the baseline similar to the result obtained by Kakihara et al.[8] and Yasuda et al.[9].
2) In an urban area, the number of common visible GPS satellites is limited at a location crowded with buildings.
3) In the FM-DGPS, a strong electric field is necessary in order to receive differential correction data even if the general FM program can receive a message in stereo.
4) The MF-DGPS showed a higher positioning accuracy than did FM-DGPS.

From the above results, it may be said that the MF-DGPS position accuracy must be high in order to guarantee the security of ship navigation.

The differential correction data update interval of the FM multiplex is clearly longer than the MF beacon. However, in this study, the FM sub-carrier receiver converted the differential correction data into the RTCM format from the DARC format. Nevertheless it cannot be said that the FM-DGPS position accuracy is not high. Principally, the FM-DGPS is intended for car navigation. Accordingly, there are times when GPS is ineffective due to the road circumstances. Therefore, in car navigation, map matching (using the assumption that a car usually runs on a road, when the observed position of the car came deviates from a road, the map matching technique revises it to the nearest road) and the use of sensors of the car steering direction and speed, or the acceleration are applied jointly, and improvement of position accuracy is attempted.

On the other hand, the use of the FM-DGPS in the coastal area is considered. It is thought that the GPS satellites that can be utilized will not be as limited in the coastal area, compared with an urban area, but the FM-DGPS service area is a problem. As described above, a strong electric field is necessary to use FM sub-carrier broadcasting data. The measurement of the service area in oceanic regions has is not been done because the FM sub-carrier broadcast is intended mainly for car navigation.

In the service area, MF-DGPS has high positioning accuracy. Then, the MF-DGPS is applicable on land in addition to at sea. However, the effective range will be narrower because the SNR is expected to be low due to the greater amount of electric wave noise in an urban area compared with at sea.

The use of the MF-DGPS on land and of the FM-DGPS at sea for a moving target must be studied next.

Acknowledgments

I am grateful to Dr. Toshiharu Kakihara for his helpful advice and timely guidance throughout this study. I wish to thank the students of the Marine Navigation Systems Engineering Section, Tokyo University of Fisheries, for cooperation in the observation.

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都市部における中波ビーコンと FM 多重放送による DGPS 測位精度の評価

宮本佳則

GPS の SPS（Standard Positioning Service）では，SA（Selective Availability）や様々な誤差要因により測位精度は約 100 m に故意に劣化させてある。しかし，ディファレンシャル方式（DGPS）を用いることで，この精度を 10 m 以下にすることができる。

現在，東京近郊の都市部で展開・利用できる DGPS サービスを大別すると，海上保安庁が行なっている中波ビーコンを用いたものと，㈱測位情報センターが行なっている FM 多重放送によるサービスである。しかし，この２つの DGPS サービスで送信される補正情報は，伝送フォーマット等が異なる。これらが測位精度へ及ぼす影響については，比較例が少なく，今後の適切な利用に向けての指針となる資料に欠けていた。そこで，これらの DGPS サービスの特徴と相違を都内陸上観測点で実測を行ない比較・検討した。

その結果，中波ビーコンによる DGPS 測位精度が FM 多重放送と比較して高いことが分かり，それぞれの DGPS 補正の都市部での受信及び測位の特徴を明らかにすることができた。

キーワード：GPS，DGPS，海上中波ビーコン，FM 多重放送，測位精度