RTK-GPS Positioning in Japan by GPS-Based Control Stations via DMCA Mobile Radio Communication System

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BIOGRAPHY

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ABSTRACT

RTK-GPS is a real time positioning system of the accuracy of one cm order with carrier phase measurement. Many applications are now under examination in Japan. The most indispensable for the positioning procedure are carrier phase data from reference stations. There is at present a mobile radio communication system operating in Japan, called DMCA (Digital Multi-channel Access) system. It can be used as a medium of dissemination of the carrier phase data. It is an 8 kbps radio system for many users on TDM/TDMA mode. Geographical Survey Institute (GSI) of Japan has established the network of as many as 947 GPS-based control stations all over the Japanese Islands for seismological researches. They are available for the system of RTK-GPS positioning through the medium of DMCA.

Experiments have been operated since October 1997 for RTK-GPS data dissemination from several GPS-based stations via DMCA both around Tokyo metropolitan region and in the Kansai district. The Trimble CMR (Compact Measurement Record) data for RTK-GPS positioning are transmitted all day long through MCA base stations which have the service area of 20-30 km in radius.

The authors tried RTK-GPS positioning first at a fixed point in Tokyo University of Mercantile Marine. The data were received from Nerima GPS-based Control Station (base line length: 17 km) by three Trimble 4000SSi GPS receivers with a single GPS antenna. It is confirmed that their performance is within the specification described by the manufacturer. Each pattern of distribution of the positions calculated by the three receivers is quite similar to each other. The 'Fix' solution rate, or the rate of fixed positions with the flag of 'Fix', is 87.7 % for 145,259 fixed positions which are calculated every second for 40 hours. The data transmission delay measures normally 1.6-1.7 s. The communication line of DMCA has originally been designed to quit sending the data every 1.5-5.0 minutes for several, often several dozen seconds, depending on the areas and the periods of time. It is widely desired that the system should be improved for continuous positioning.

Another experiment was carried out comparing the positioning by two GPS receivers and a single fixed antenna which receive the data for 3.3 hours from two different GPS-based control stations, at Nerima and Kawasaki, respectively 17 and 16 km away from the user GPS antenna. The rate of 'Fix' solution is 93.9 % and 52.4 %, respectively. The difference between their

average positions is 3.28 cm in latitude, 1.44 cm in longitude and 0.91 cm in altitude. 2drms against the average points is 2.63 cm and 3.60 cm, and S.D. in altitude is 2.08 cm and 2.83 cm, respectively. The low rate of 'Fix' solution by Kawasaki GPS-based Control Station is supposed to be due to the excess of data transmission delay over 2.0 s, which is observed approximately every other second. It seems that the transmission delay should be within 2 s in order to get 'Fix' solution by Trimble 4000SSi's. There must be some technical problems to be solved in the communication system from Kawasaki GPS-based CS through Shinyokohama MCA Base Station.

Next, they tried the positioning on board a ship navigating in Tokyo Bay. They confirmed that it works well.

1 INTRODUCTION

RTK-GPS (Real Time Kinematic GPS) is a real time satellite positioning system. The range to the satellite from a user GPS antenna determined by the phase measurement of the carrier waves from the GPS satellites is of the order of mm in S.D. Thus the accuracy of a few cm order can be easily obtained in 2drms. The system is easier to operate than such a traditional system as 'Total Station'. Many applications have been investigated in Japan[1][2].

RTK-GPS needs a data communication line for carrier phase data transmission from a reference station settled at a known position to a user receiver. In Japan they have mainly used a specific low electric power radio communication device, which does not require license. Accordingly, the data transmission area is limited to just several hundred meters in radius from the reference station. It is hard for them to bear the burden of preparing expensive GPS receivers. Furthermore it is technically difficult to settle and survey a reference station, whose position is to be obtained by less than one cm order. So RTK-GPS users in Japan have desired the development of a wider and less expensive dissemination service.

RTK-GPS carrier phase data dissemination service has been operated experimentally since October 1997. There are several GPS-based control stations transmitting the data on a mobile radio communication system, called DMCA (Digital Multi-channel Access[3]), supported by the National Mobile Radio Centers Council of Japan, similar to Trunk Radio System in European countries. They are among 947 GPS-based stations established by Geographical Survey Institute (GSI) of Japan in order to observe crust movement for seismic prediction.

The authors tried RTK-GPS positioning using the present experimental DMCA system and evaluated its validity. First they acquired the basic positioning data at a fixed point in their university and then those on board a ship under navigation.

2 SYSTEM OUTLINE

2.1 GPS-BASED CONTROL STATION

The carrier phase data for RTK-GPS positioning have been transmitted experimentally from several GPS-based control stations, which work as the reference stations of RTK-GPS via DMCA. The service is available at the moment in the following districts: the Kanto (Tokyo and the surrounding prefectures), the Kansai (Osaka and Nara, Hyogo prefectures), the Tokai (Aichi, Gifu, Mie and Shizuoka prefectures) and a part of Hokkaido prefecture.

Figure 1 shows the allocation of the GPS-based control stations. They have been operated by GSI. The institute has established the network of 947 GPS-based stations, called GEONET (GPS Earth Observation Network), for surveying and seismological researches, which covers almost all of the Japanese archipelago with the geometrical interval of about 30 km.

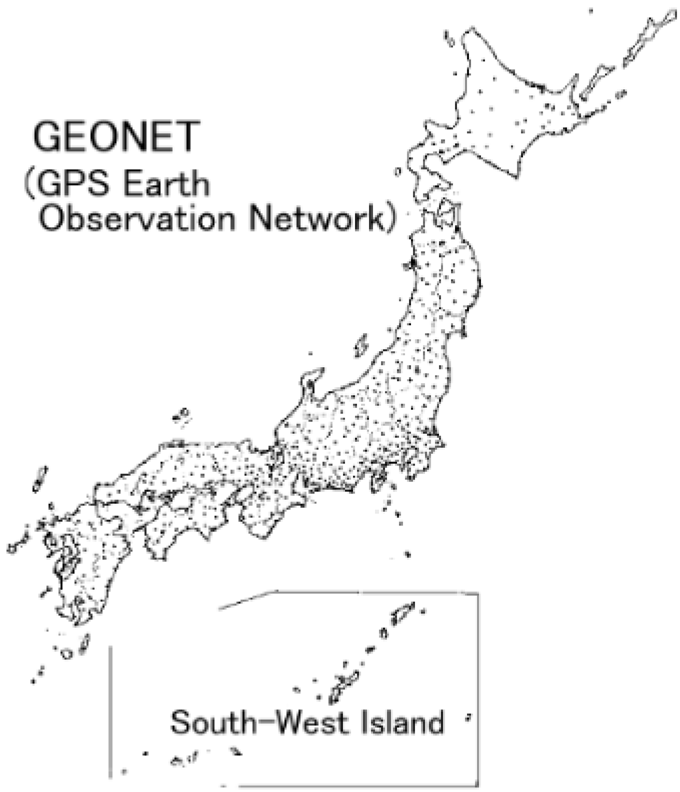

Figure 1 Allocation of GPS-Based Control Stations in Japan

Photo 1 shows an appearance of a GPS-based control station. The station is equipped with a GPS receiver, meteorological observation instruments and data communication apparatus. They are contained in a 5-meter stainless-steel tower. The GPS antenna is set up on the top.

Photo 1 GPS-Based Control Station

The format of the carrier phase data is of CMR (Compact Measurement Record), defined and published by Trimble Navigation Limited at ION GPS-96. The volume of CMR data is about 1.0 kbit/set, which is the average of about 30 minutes' data transmitted every second by a Trimble 4000SSi. On the other hand, RTCM SC-104 defines the Message Type 18, 19 for the carrier phase data transmission format by the document of the version 2.1. The format requires that you should transmit the volume of about 3.9 kbit/set every second. Compared with CMR, the format is inefficient in transmitting data. It is expected RTCM will publish soon a more efficient format, version 3.0.

Most of RTK-GPS receivers accept data only if they are processed in the format developed by their own manufacturers. The publication of the format by such a private company as Trimble is to be highly evaluated. It will naturally lead to the standardization of the carrier phase transmission format in the not too distant future.

2.2 DMCA COMMUNICATION SYSTEM

The service of MCA system in Japan for business mobile radio communication started in 1982, and its digitalized system (DMCA) was introduced in 1994. There are now about 600 thousand mobile and portable terminals. The system has been operated experimentally for the transmission of CMR data since October 1997.

Table 1 shows the main specifications of DMCA. The communication is carried out between office stations and mobile terminals, or between the terminals, via a MCA base station with the service area of about 30 km radius for many users. A specific frequency used to be shared by only a pair of users to hold radio carried out between many users on a single frequency. The system works efficiently. The data transmission rate is wholly 64 kbps with 6 channels of 8 kbps on TDM/TDMA mode. The system is designed to quit communication every 1.5-5.0 minutes, depending on the area and the time zone so that a single frequency can be shared by as many users as possible.

Table 1 Main Specification of DMCA

Item	Value
Frequency	1.5 GHz
Data Rate (Whole System)	64 kbps
Data Rate (Per Channel)	8 kbps
Multiplex Mode	TDM/TDMA
Multiplex Channels	6

Figure 2 shows the schematic figure of data transmission on DMCA. First, at a GPS-based control

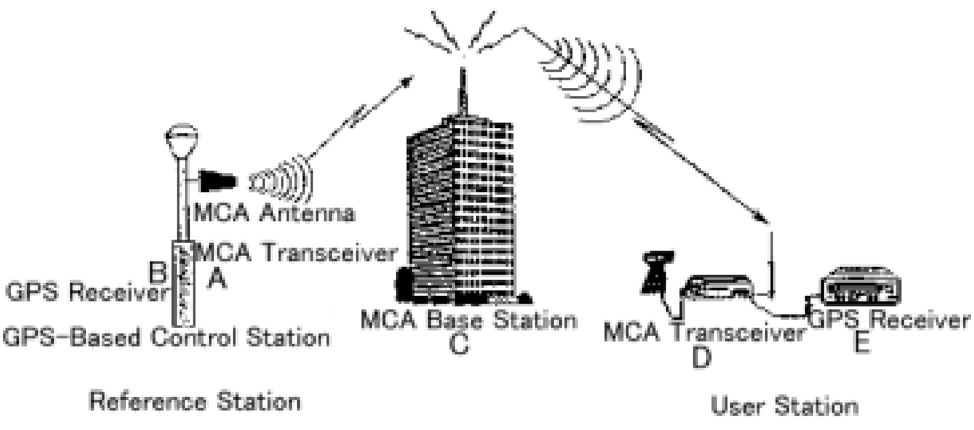

Figure 2 Schematic Figure of Data Transmission by DMCA

station after receiving CMR data transmitted from the GPS receiver (B), the MCA transceiver (A) requests the MCA base station (C) to assign a channel, and then it transmits the CMR data every second through the specified channel to the MCA base station (C). In the meantime, the MCA transceiver (D) at the user station requests the MCA station (C) to assign a channel through which to receive the CMR data. The MCA transceiver (D) checks the data by CRC (Cyclic Redundancy Check) and further by BCC (Block Check Character) added by the MCA transceiver (A) to detect transmission errors. If it detects no error, the transceiver (D) transmit the CMR data to the GPS receiver (E) at the user station. If any error is detected, the data are abandoned.

Photo 2 shows the MCA transceiver and the antenna.

Photo 2 MCA Transceiver and Antenna.

Figure 3 shows the format for the data transmitted on DMCA. The transmission rate is 64 kbps for every frequency. One frequency is multiplexed into 6 channels on TDM/TDMA mode, each of which repeats every 90 ms for a period of 15 ms, so the transmission rate for every channel is reduced to 8 kbps. As it includes a "Preamble" for synchronization, CRC and BCC, the practical rate seems to fall to much less than 8 kbps. In the near future you can use several channels at once so that you may get higher rate.

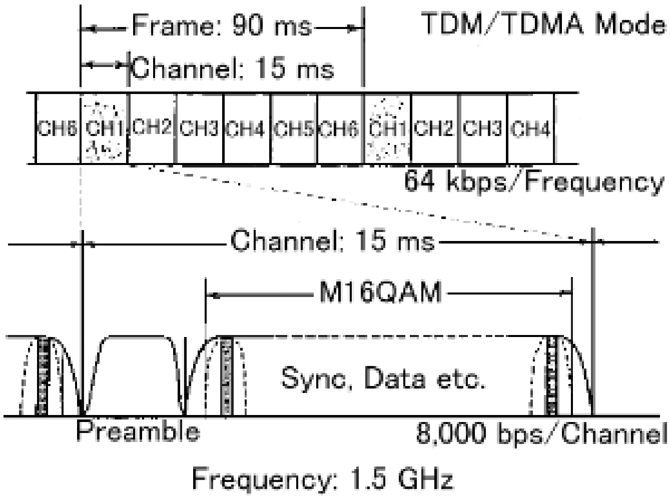

Figure 3 Format of the Data Transmitted by DMCA

3 BASIC EXPERIMENT

Before running RTK-GPS positioning experiment on board a navigating ship, they tried to measure the data transmission delay and evaluate the accuracy of positioning for a fixed point on land in Tokyo University of Mercantile Marine (TUMM).

Figure 4 shows where the GPS-based control stations and the MCA base stations used in the experiment are allocated. CMR data from Nerima GPS-based Control Station are transmitted through Shinjuku MCA Base Station and those from Kawasaki Control Station through Shinyokohama MCA BS.

Figure 4 Allocation of GPS-Based Control Stations and

MCA Base Stations Used in the Experiment

3.1 DATA TRANSMISSION DELAY

RTK-GPS is requested to give a real time performance. The GPS receiver used here is a Trimble 4000SSi. It calculates its own position for about 2 s on a synchronized mode, by comparing the carrier phase data measured at the mobile station with CMR data transmitted from the GPS-based control station. The calculated result is outputted with the delay of 2.0-2.5 s, therefore if the data transmission delay exceeds 2 s, no result is outputted.

The authors tried the measurement of the delay by DMCA first. Delays were measured between the 1PPS (pulse per second) from the GPS receiver and the head of CMR data inputted to user's 4000SSi, using a universal counter 5313A (resolution: 50 ns) by Hewlett-Packard Co., Ltd. As well known, the 1PPS is outputted every second sharp, and the carrier phase data from satellites are measured at the GPS-based station synchronously. Although the present measurement cannot help producing ambiguity of seconds, you are able to measure the fractional second of the delay very accurately.

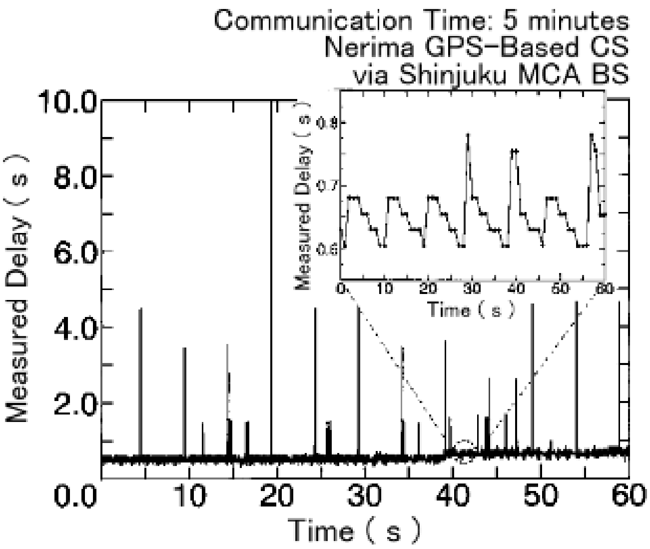

Figure 5 An Example of the Time Series of Data Transmission Delay Measurement by DMCA

Figure 5 shows an example of the time series of data transmission delay measurement. The long vertical lines indicate the transmission is suspended every 5.0 minutes. The communication line of DMCA is designed to quit sending data so as to provide the link to as many users as possible. It takes several, often several dozen, seconds to recover. Since no 'Fix' solution can be obtained during the period of the deficit, the ratio of 'Fix' solution to the total positioning falls to less than 100 %. The figure also shows a part of data transmission delay on an enlarged scale. The periodical variation shown in the figure seems to have been induced by the asynchronous operation of DMCA data transmission packet with CMR data. The figure indicates that the data transmission delay varies within 0.2 s, while the data flows continuously.

Figure 6 shows an example of the time series of the measured delay of data transmission from Nerima GPS-based CS via Shinjuku MCA BS and those of Kawasaki CS via Shinyokohama MCA BS. The time axis is enlarged in comparison with figure 5. In the present measurement, the duration of continuous data transmission on DMCA is 2.0 minutes. Figure 6 as well as figure 5 shows that the delay becomes longer, every time the data transmission is suspended. But in the case of Kawasaki GPS-based CS, there is a large amplitude variation. The delays of 1.6 and 2.1 seconds arise almost alternatively. The authors conceive there are some problems to be solved in the transmission line from Kawasaki GPS-based CS, comparing with the result of the small variation of the Nerima GPS-based CS. What and where they are is now under examination.

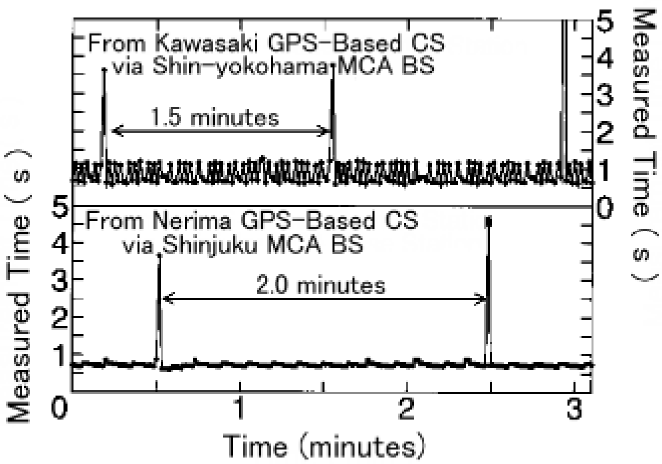

Figure 6 An Example of the Time Series of Data Transmission Delay Measurement by DMCA

3.2 RTK-GPS AT A FIXED POINT ON LAND

Figure 7 shows the experimental configuration of RTK-GPS positioning. First the authors tried positioning at a fixed point on land in Tokyo University of Mercantile Marine. The GPS antenna is about 20 m high above the mean sea level on the roof of a 5-storied building. Simultaneous positioning was tried with three 4000SSi's and a single GPS antenna, using CMR data transmission from Nerima GPS-based CS (base line length: 17 km).

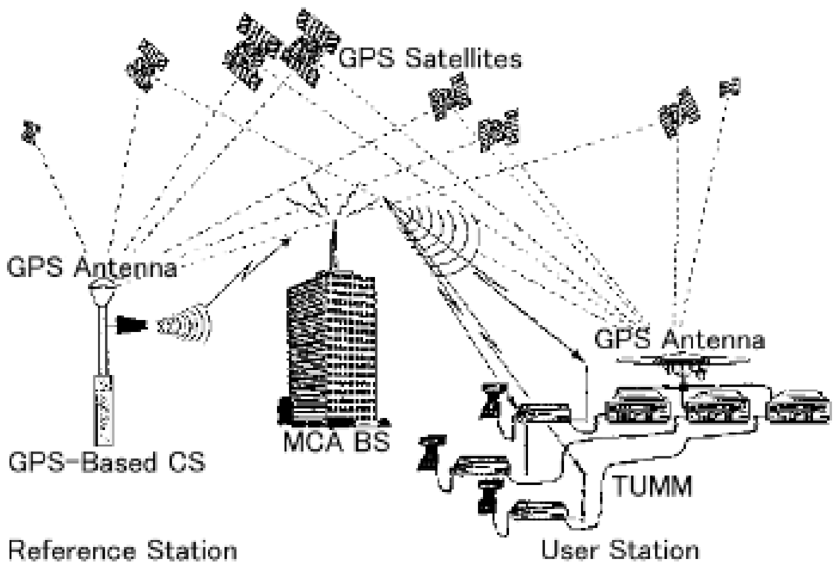

Figure 7 Experimental Configuration at a Fixed Point

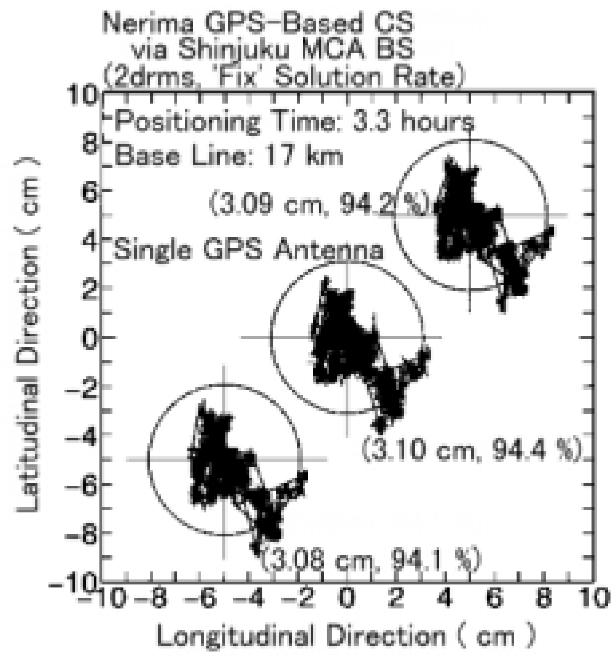

Figure 8 Horizontal Distribution Using CMR Data Transmission from Nerima GPS-Based Control Station

Figure 8 shows the horizontal distribution of positioning. In order to show the coincidence clearly, the positions calculated by the three receivers are displayed with 5 cm differences of average points in both latitudinal and longitudinal directions. Figure 9 shows three temporal series of variation in altitude with 30 cm offset of average values. The positioning accuracy were respectively 3.09 cm, 3.10 cm and 3.08 cm in 2drms, and 3.88 cm, 3.89 cm and 3.88 cm in S.D. of altitude. The three patterns of positioning distribution both in 2drms and S.D. are coincident with each other. Thus the three receivers are confirmed to show remarkable resemblance in their performance. Their ‘Fix’ solution rate is 87.7 % every second for more than 20 hours’ positioning.

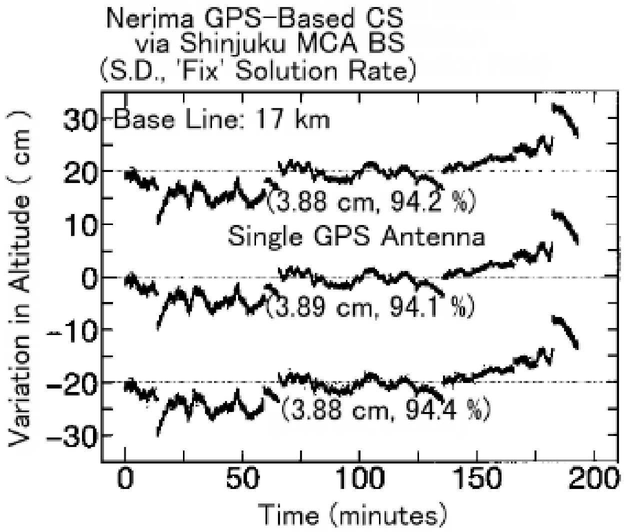

Figure 9 Temporal Series of Variation in Altitude Using CMR Data Transmission from Nerima GPS-Based Control Station

The present system uses GPS-based stations as the reference. Next, the authors investigated how the two groups of fixed positions agree, by using CMR data transmitted from the different two GPS-based stations. They tried RTK-GPS positioning simultaneously with two receivers and a single antenna, using CMR data transmitted from Nerima and Kawasaki GPS-based CS. The base line length is 17 and 16 km, respectively.

Figure 10 shows the horizontal distribution of the fixed positions during about 3.3 hours' positioning. The lines connect the points which are fixed by reference to Nerima GPS-based CS, and the dots are those given by reference to Kawasaki GPS-based CS. Their 2drms is 2.63 cm and 3.60 cm, respectively. Figure 11 shows a temporal variation of altitude. S.D. is 2.08 cm and 2.83 cm, respectively. Although both receivers share one single GPS antenna, the average values of the fixed points show some discrepancy. The difference is respectively 3.28 cm, 1.44 and 0.91 in latitudinal, longitudinal and altitudinal directions. 'Fix' solution rate is 92.8 % and 57.2 %, respectively for the two GPS-based stations. The authors are astonished by the small discrepancies, considering that the length of the base lines is far beyond the distance specified by the manufacturer.

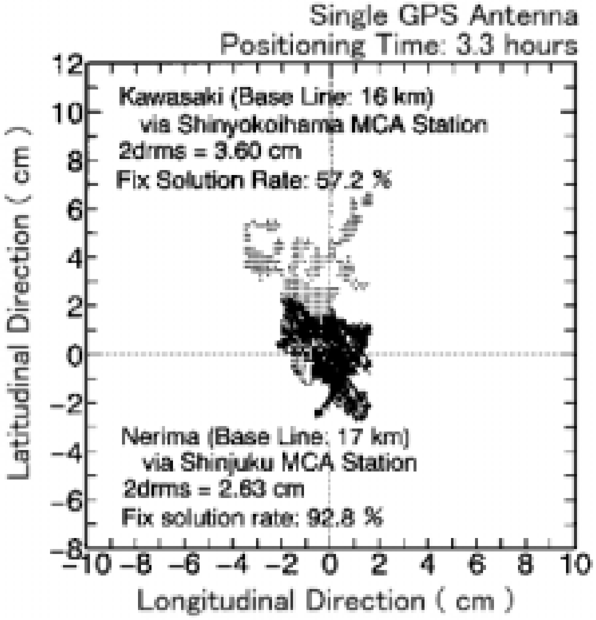

Figure 10 Horizontal Distribution of Positions Fixed by Reference to Nerima and Kawasaki GPS-Based Control Station

Table 2 shows the positioning result at a fixed point on land in TUMM. The authors tried RTK-GPS positioning for more than 10 hours, making reference to both GPS-based stations. With Kawasaki GPS-based CS, the 'Fix' solution rate is much lower than with Nerima GPS-based CS. It implies that the data transmission delay from Kawasaki GPS-based CS often exceeds 2 s.

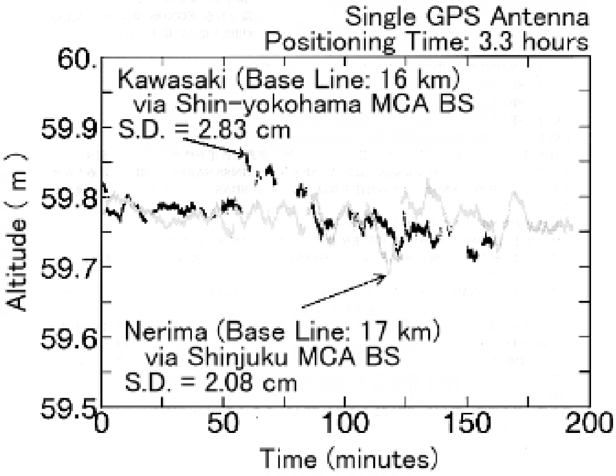

Figure 11 Temporal Series of Altitude Fixed by Reference to Nerima and Kawasaki GPS-Based Control Stations

Table 2 Positioning Result at a Fixed Point with the Data from GPS-Based CS

Reference Station	Nerima GPS-Based CS	Kawasaki GPS-Based CS
Base Line	16,988 m	15,700 m
Time	12.9 hour	11.7 hour
'Fix' Rate	93.9 %	52.4 %
2drms	3.29 cm	3.05 cm
Altitude S.D.	3.58 cm	2.20 cm

DMCA is designed to quit connection every 1.5-5.0 minutes and it takes several to several dozen seconds to recover. So the 'Fix' solution rate is always below 100 %. In order to be practically usable, the system must be improved to keep data transmission without interruption.

4 RTK-GPS POSITIONING UNDER NAVIGATION

The authors tried RTK-GPS positioning and collected the basic data on board a ship under navigation.

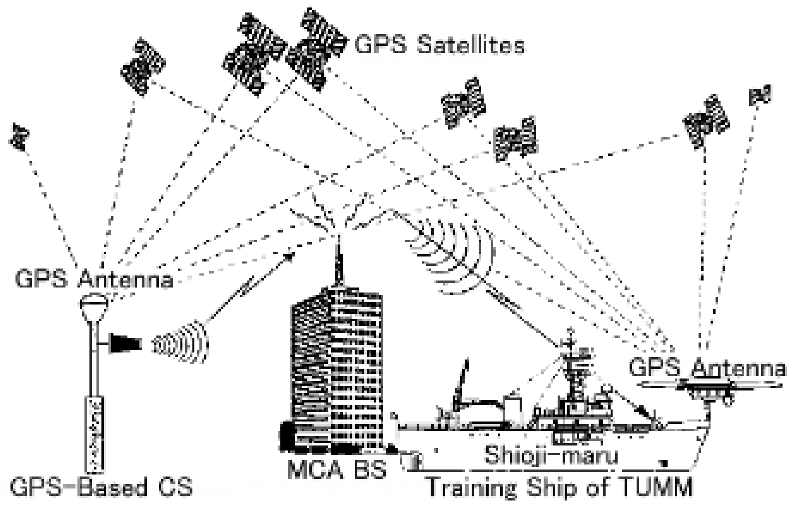

Figure 12 Experimental Diagram of On Board Positioning

4.1 EXPERIMENTAL OUTLINE

Figure 12 shows the experimental diagram. They tried on board RTK-GPS positioning in Tokyo Bay on the training ship Shiojimaru (photo 3), which belongs to TUMM.

Photo 3 Training Ship Shiojimaru Belonging TUMM

Photo 4 shows the GPS antenna set up on the top of the flag post on her bow. The positioning was tried every second with a 4000SSi mobile receiver and a single GPS antenna, using CMR data from Kawasaki GPS-based CS.

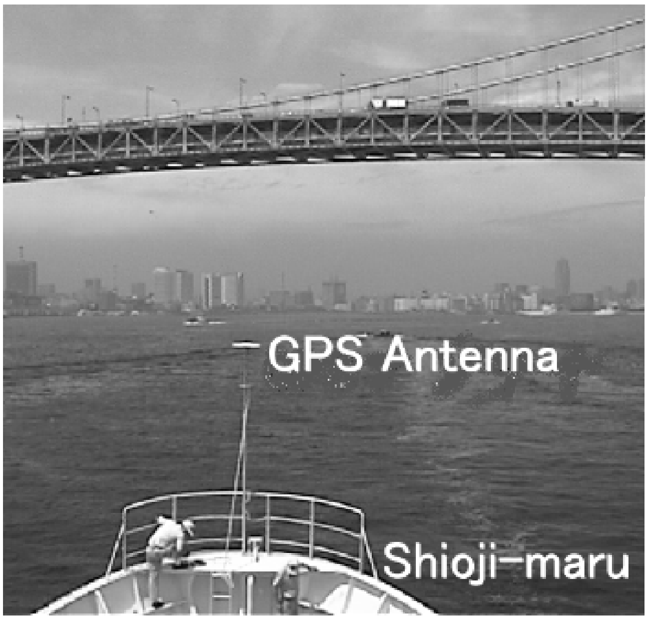

Photo 4 GPS Antenna on the Top of Flag Post of Shiojimaru

If you cannot find another convenient reference near by, it will be extremely hard to evaluate the accuracy of on board positioning. The authors used another 4000SSi mobile receiver with the same GPS antenna to calculate by the CMR data transmitted via mobile phone from another reference station settled in Tokyo University of Mercantile Marine. The reference position at TUMM had already been determined by positioning every second for 3 hours with a 4000SSi, by using CMR data from Kawasaki GPS-based CS. Since the 2drms measures 2.68 cm, it is confirmed the reference station in TUMM has the accuracy of cm order.

As shown in photo 5, the mobile phone was settled at the cabin window of the training ship navigating in Tokyo Bay, so the ideal data were not obtained. Data transmission rate by the mobile phone is 9,600 bps.

Photo 5 Mobile Phone at the Cabin Window

4.2 RESULT AND DISCUSSION

Figure 13 shows the result of on board RTK-GPS positioning. The experimental ship Shiojimaru steamed through Uraga-channel to the offshore of the Port of Kawasaki, and after taking 2 U-turns there, entered the Port of Tokyo.

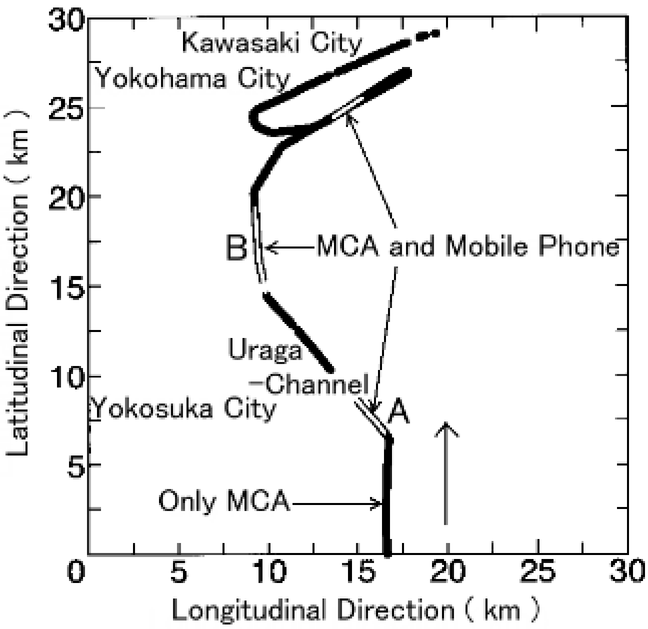

Figure 13 On Board Positioning Result Under Navigation

The line shows the route on which GPS positioning was tried using CMR data transmitted on DMCA from Kawasaki GPS-based Control Station, about 5-30 km away from their experimental area. The white parts of the line indicate where positions were calculated both by mobile phone data transmission from the reference in TUMM station and by DMCA. The base line from the reference in TUMM was very long, more than 20 km. But it is confirmed that RTK-GPS positioning is practicable in so wide an area as Tokyo Bay. The lower ‘Fix’ rate of mobile phone positioning may have been due to a weak electric field at the cabin window where the mobile phone was settled.

Table 3 shows S.D. and the averaged differences between positions fixed simultaneously by DMCA and mobile phone, on the 2 parts of the route, denoted by A and B in figure 11. The positioning time was about 2.5 hours by DMCA and 1.5 hours by mobile phone. ‘Fix’ solution rate is 54.3 % and 79.7 %, respectively. The low ‘Fix’ rate with DMCA system is not unreasonable, for a low rate is also observed at the fixed point in our university, which seems due to a periodical enlargement of data transmission delay from Kawasaki GPS-based CS. On the other hand, in the case of positioning by mobile phone data transmission, the position of the mobile phone antenna is supposed to have been inappropriate.

Table 3 S.D. and Averaged difference between positions simultaneously Fixed, Using CMR Data Transmitted by DMCA and Mobile Phone, Under Navigation

	Place	S.D.	Discrepancy
Horizontal	A	2.82 cm	99.9 cm
	B	3.28 cm	26.7 cm
Altitude	A	5.13 cm	62.3 cm
	B	7.00 cm	112.7 cm

S.D. of the difference between the positions fixed by DMCA and mobile phone is both 2-3 cm in the horizontal distribution. But the offset is of as many as several dozen cm. The ambiguity may have been due to the excessively long base line of the mobile phone positioning.

5 CONCLUSION

The authors tried RTK-GPS positioning with two receivers and a single GPS antenna, using two GPS-based control stations of Geographical Survey Institute of Japan to refer to RTK-GPS carrier phase data transmitted on DMCA mobile radio communication system. The positions fixed by two GPS-based stations for 3.3 hours were compared with each other to get the average values and S.D. The result shows that 2drms is a few cm and that the averaged positions are discrepancy by a few cm. DMCA is designed to quit connection every 1.5-5.0 minutes and it takes several seconds to recover. This prevents the receivers from obtaining the ‘Fix’ solution rate of 100 %. Improvement is desired so that continuous linkage may be made feasible.

Next, they tried on board positioning in Tokyo Bay. Although there was no absolute reference to evaluate the accuracy, it is confirmed that RTK-GPS positioning is practicable in so wide an area as Tokyo Bay. This experiment was organized for the basic research of RTK-GPS positioning. But they evaluate that this positioning system can aid satisfactorily in real time anchor watching, automatic berthing and entry into port, near the Ports of Tokyo and Yokohama.

It is expected that the service areas will grow wider in future. They hope that this experiment will help to promote practical use of RTK-GPS positioning system in Japan.

ACKNOWLEDGMENTS

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