Vehicle Positioning by Network-Based RTK-GPS Using Area Correction Parameter (FKP) via TV Wave in Japan

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BIOGRAPHY

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ABSTRACT

The precision of a few centimeters can be easily obtained by RTK-GPS positioning, as the range from a user GPS antenna to the satellite is determined by the phase measurement of the carrier waves. It is necessary to provide the correction data included the carrier phase data from a reference station located at a known position, to a user receiver.

In the present paper, ASC (TV Audio Sub-carrier Channel) of the television wave is used for transmitting the FKP data to test the network-based RTK-GPS. The carrier phase data of every second from GPS receivers at four reference stations are transmitted to the Data Station via the Internet and processed to the FKP data to be transmitted to the user stations. The TV broadcast can be disseminated the data for the wider area and the great many users simultaneously.

The authors investigated the network-based RTK-GPS positioning at a fixed point in the Tokyo University of Marine Science and Technology, located outside the reference station network area. The 2drms of the horizontal positions of 2.95 cm by ASC is comparable to the 3.14 cm simultaneously obtained by the public phone link. They also tried the positioning on running vehicles of a driving car in Tokyo urban area and a sailing boat in Tokyo Bay. It is shown in the former that the fixed positions were available, though the number of satellites varied frequently by the blocking of tall buildings. In the latter, the positions, fixed continuously with the middle range baseline by the data of FKP, agreed well with those fixed by traditional RTK-GPS.

The results prove that the ASC is capable to be the future potential medium for supporting the precise real time GPS positioning service.

1. INTRODUCTION

RTK-GPS (Real Time Kinematic GPS) is a real time and precise positioning system with GPS satellites. The range to the GPS satellite from a user antenna is determined by the phase measurement of the carrier wave from the satellite with the precision of millimeters. Thus the high precision positions of the order of a few centimeters are easily available. Furthermore, the system is easier to operate than a traditional survey system as Total Station. So many applications of RTK-GPS have been investigated in Japan[1][2].

A fast data communication link is needed to transmit the carrier phase data from a reference station located at a known position to a user receiver for the real time operation. A low power radio communication device and a cell phone system are usually used in Japan because they do not require a license. However, the data transmission area is inevitably limited in the former to just several hundred meters in radius from the reference. The charge is very expensive in the latter for the continuous operation Furthermore it is technically difficult to establish a reference station, whose position is to be obtained to the accuracy less than one centimeter. And besides, it is hard for users to purchase the expensive GPS receivers for the reference station additionally. It is well known that the base line is limited to about 10km in RTK-GPS due to the non-uniformity of the ionosphere and the troposphere. Hence the users who need high precision and real time positioning have desired the development of a flexible and inexpensive dissemination service [3][4].

A carrier phase data dissemination service in RTK-GPS was operated experimentally in late 1990s in Japan. There were several GPS-Based Control Stations (GPS-Based CS) transmitting the correction 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 the Trunk Radio System in European countries.

They were among 1200 GPS-Based CS established at present by the Geographical Survey Institute (GSI) of Japan in order to observe crustal movement for seismic prediction. And since December 2000 for about one year, three types of network-based RTK-GPS[5], the MultiRef of the Calgary University in Canada, the Virtual Reference Station (VRS) of the Trimble Terrasat and the Reference net of the Geo++ GmbH in Germany known as FKP[6] (flachen-korrectur-parameter) system, were operated experimentally and simultaneously in Tokyo area. The methods had been well tested and evaluated by many groups of surveyors and navigation engineers.

The FKP method is now recognized as standard configuration in the satellite positioning services, like SAPOS (German National Survey Satellite Positioning Service).

On the other hand, the TV Audio Sub-carrier Channel (ASC; audio-multiplexed-data broadcast of TV wave), which is capable to transmit the data as fast as 16 kbps, can provide a wide frequency band to disseminate the carrier phase correction data for many users in a wide area. We can receive the data using just the ordinary TV antennas, receivers and data decoder.

The authors disseminated the FKP data by TV ASC to investigate the network-based RTK-GPS positioning. The GEO++ system is suitable for the dissemination type of data transmission. It does not require dual-directional communication. We received the FKP data and investigated the performance at a fixed point on the ground in Tokyo University of Marine Science and Technology (TUMST) in Shinagawa, Tokyo, located outside the reference station network area. The authors evaluated their validity by applying the data to network-based RTK-GPS positioning. Furthermore, the authors tried positioning on running vehicles of a driving car in Tokyo urban area and a sailing boat in Tokyo Bay.

2. SYSTEM OUTLINE

2.1 Network-Based RTK-GPS System Using FKP

Figure 1 shows the basic concept of the network-based RTK-GPS. The system is comprised of more than 3 reference stations, a “Data Control Center (Data Center)” and user stations. The carrier phase data from at least 3 reference stations are transmitted to the Data Center. And they are converted to FKP data there. Then, it is transmitted to user stations via data communication line.

Several reference stations in a wide area observe GPS satellites all in view simultaneously, so it is possible to correct the effect of ionosphere in the wide area (for example, about 60 km between reference stations). It is possible to fix a position by RTK-GPS based on a carrier phase measurement in the wide area surrounded by the reference stations.

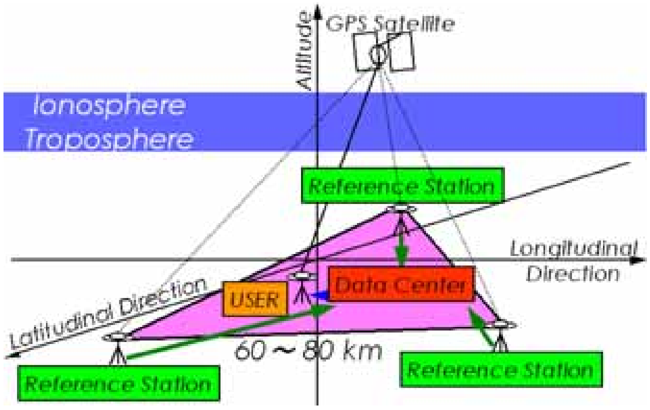

Figure 1 Diagram of the Network-Based RTK-GPS

2.2 TV Audio Sub-carrier Channel (ASC)

The TV Audio Sub-carrier Channel (ASC) can disseminate the carrier phase correction data for many users across a wide area. It can receive the data using ordinary TV antennas and can transmit the data as fast as 16 kbps.

Figure 2 shows the frequency spectrum of the TV audio frequency band. f_H is the horizontal scanning frequency of the TV pictures, 15.734264 kHz. There are 2 audio sub-carriers, in addition to the audio main channel (L+R) and sub-channel (L-R) for stereophonic and bilingual broadcasting. A wide frequency band can be used for the data transmission. The red ($4.5f_H$) and blue ($7.5f_H$) sub-carriers (data channel) are modulated by DQPSK (Differential Quadrature Phase Shift Keying) to allow respectively a rate of 16 kbps.

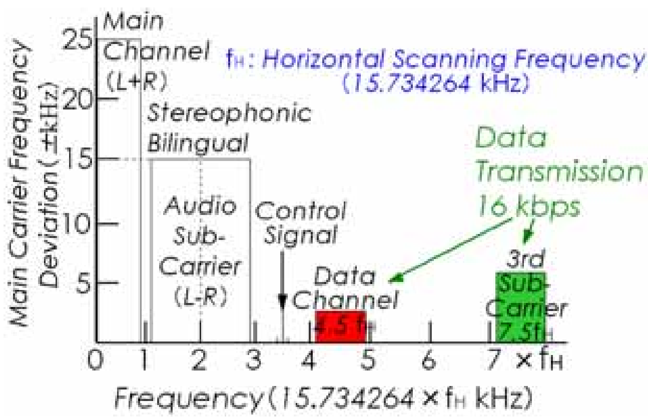

Figure 2 Frequency Spectrum of the TV Audio Band

Figure 3 shows the format of a frame for the data transmitted by ASC of TV wave. The data is put the pink data section of 152 bits, horizontally. They are sent out vertically by the bit interleave for each frame consisted of 32 packets to minimize the effect of the burst noise error. After they arrive at the user, they are reconstructed to the original form shown in Fig. 3. Then the errors are detected and corrected by the horizontal checking code, CRC (Cyclic Redundancy Check) and CHC (CHeck Code) for each packet. The data transmission period is 0.577 s by ASC(16 bits + 288 bits/packet * 32 packets) / 16 kbps = 0.577 s).

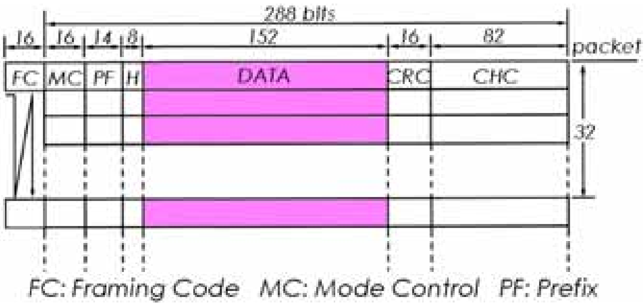

Figure 3 Format of a Frame for the Data Transmitted by ASC of TV Wave

Figure 4 shows the time to require the data transmission via ASC. We measured them by transmitting the data of GPS receiver at our laboratory every second via public phone line and receiving the disseminated data via ASC at the original point. They are distributed randomly between 0.740 s and 1.317 s. The shortest includes the time for transmitting one frame data (0.577s) of ASC [6] and the processing time of the data transmitting modem (0.163s). It corresponds to the case that the data arriving via public phone coincides with the timing of frame starting. The longer case the data need to wait the start of next frame. The waiting time is the period of one frame of 0.577 s at most. Thus the maximum delay is 1.317 s. These are measured independently of the present positioning experiment just to see the transmission time.

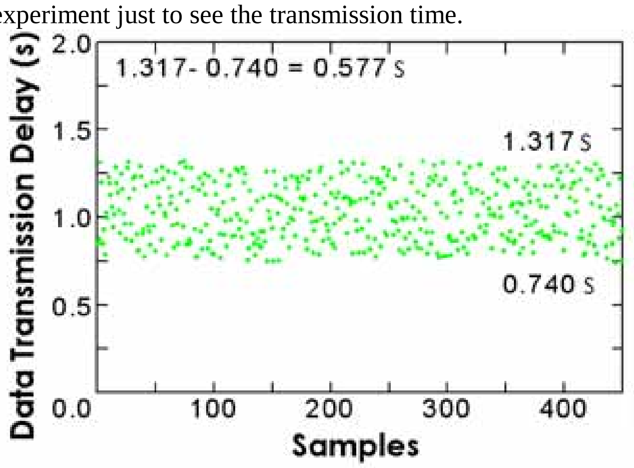

Figure 4 Data Transmission Delay by Using ASC

Figure 5 shows the service area of the data broadcast in Kanto region by ASC. The small green circles are the relay stations of the TV broadcast. Now, the ASC transmits the data from Tokyo Tower with the service area of about several km in radius for the mobile users. They can receive the data easily by whip antenna. Using Yagi antenna enlarges the radius area to about several hundred km for many fixed users. Photo 1 shows the ASC receiver, ASC2001. The width, height and depth are 195*25*132 mm respectively. It decodes the data from the analogue audio signal of TV broadcasting.

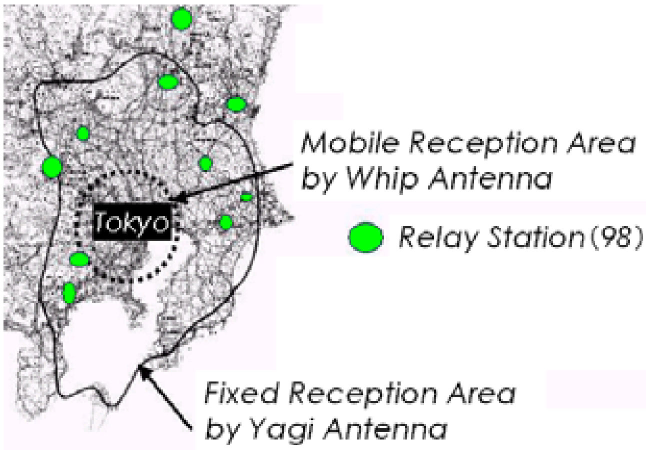

Figure 5 Service Area of the Data Broadcast by TV ASC

Photo 1 Appearance of the ASC Receiver (ASC2001)

3. NETWORK-BASED RTK-GPS POSITIONING AT FIXED POINT ON THE GROUND

Figure 6 shows the diagram of data flow for the present experimental system. We acquire the carrier phase raw data from GPS receiver at four reference stations every second at first. They are transmitted to the Data Control Center (Data Center) via Internet line. The FKP data are produced from four carrier phase data sets. The RTK positioning with the FKP data was carried out for the accuracy monitoring in the Data Center. They are transmitted to the Engineering Development Center at the TV Asahi Corporation in Roppongi, Minato-ku, Tokyo, and are disseminated from Tokyo Tower after they are multiplexed into the TV audio sub-carrier.

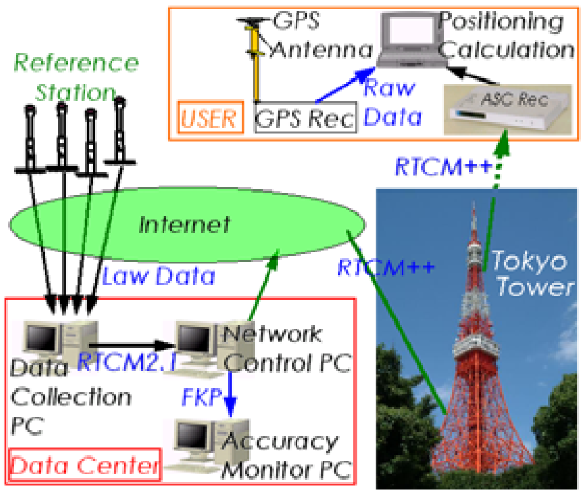

Figure 6 Diagram of the Units and the Data Flow of the Whole Experiment System

Photo 2 Scenery of the User Station included GPS Receivers, ASC Receiver and Laptop PC for Network-Based RTK-GPS Positioning Calculation in the Tokyo University of Marine Science and Technology in Shinagawa ,Tokyo

Photo 3 GPS Antenna Settled on the Roof of a Five-Storied Building at the Tokyo University of Marine Science and Technology

The data received by usual TV antenna and decoded by the ASC receiver at the user station are introduced to the laptop PC installed by the software of the Geo++ under the OS of Windows NT.
Photo 2 shows the scenery of the user station included GPS receivers, ASC receiver and laptop PC for the network-based RTK-GPS positioning calculation in the TUMST. The GPS receiver used here is a Legacy GGD. The antenna was settled on the roof of a five-storied building at the TUMST (Photo 3).
Another data transmission line of public phone line is prepared for the reference. The GPS signals were distributed to two GPS receivers via the signal splitter. The receivers only produce the raw data of the carrier phase and the stand-alone positioning results ($GPGGA sentences of NMEA). They do not calculate the precise positions of RTK-GPS. The positioning is carried out by laptop PC installed with the software of the Geo++. It needs the approximate location of a user station to convert FKP into the phase data relation to the near user station. Legacy receiver must produce at first the data of the single positioning result ($GPGGA), and the carrier phase raw data. The RTCM++ data shown in Table 1 are transmitted from the Data Center via both of the ASC of the TV broadcasting and the public phone line. The data rate of the public phone line is 9.6 kbps. The two PCs carried out the network-based RTK-GPS positioning using the RTCM++ data via both ASC and public phone simultaneously.
Photo 4 shows TV antenna (Rod Type) was settled at the banister on the roof of a five-storied building in TUMST.

Table 1 RTCM++ Data included FKP

RTCM Type	Time Interval	Contents
1	1 s	Pseudo Range Correction
3	29 s	Reference Station Parameter
14	61 s	GPS Time
16	499 s	Reference Station ID
17	120 s	Ephemeris
59	1 s	Carrier Phase Data Precise Pseudo Range Correction FKP Data

Photo 4 TV Antenna (Rod Type) Settled on the Banister on the Roof of a Five-Storied Building in the Tokyo University of Marine Science and Technology in Shinagawa, Tokyo

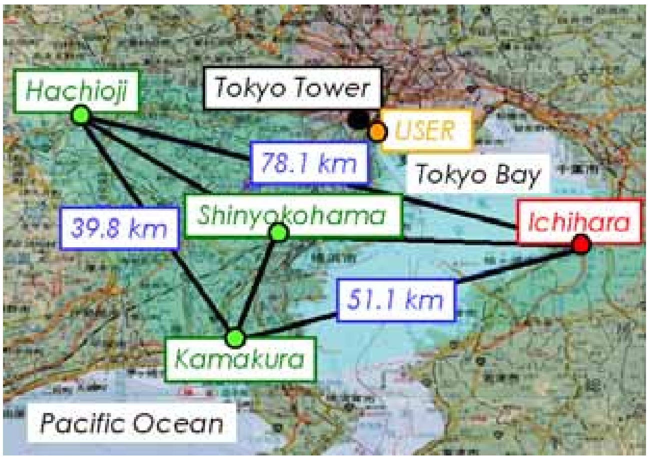

Figure 7 Allocation of 4 Reference Stations in the Experiment

Figure 7 shows where the four reference stations used in the present experiment are allocated. The stations are at Shinyokohama, Hachioji, Kamakura and Ichihara. The distances between three stations except Shinyokohama, which located middle of the triangle, are 78.1, 39.8 and 51.1 km, respectively. The user station in the TUMST is about 30 km from Ichihara main station. The positioning of network-based RTK-GPS is carried out outside network.

Figure 8 shows the horizontal distribution of the fixed positions for about 100 minutes' positioning for a fixed point on the ground of the TUMST. The values in 2drms of the horizontal distribution of the fixed positions are 2.95 cm by using ASC and 3.14 cm by using the public phone respectively. The nominal positioning precision of the traditional RTK-GPS is 2 cm plus the baseline length times 2ppm, within a radius of about 10 km from the reference station. Although the sites to which baseline length from the main reference station, Ichihara exceeds 30 km and located outside the station network area, the remarkable precision was achieved comparable to the traditional RTK-GPS positioning. These are accomplished by both ASC and public phone data transmissions. The average TTFF (Time To First Fix) by the ASC was 1.2 times longer than that of the public phone line.

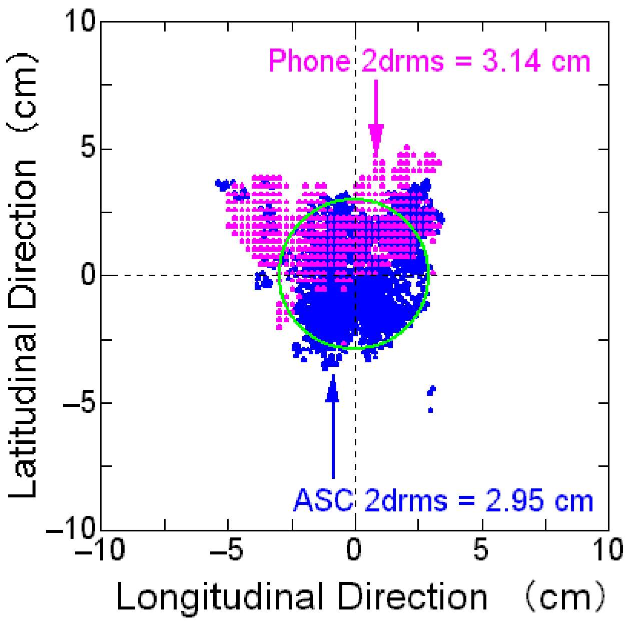

Figure 8 Horizontal Positioning Distribution at a Fixed Point on the Ground in the Tokyo University of Marine Science and Technology

4. VEHICLE POSITIONING ON RUNNING VEHICLES

4.1 Positioning on a Driving Car

Next, the authors tried the network-based RTK-GPS positioning by using FKP data transmitted via ASC while driving a car in the Tokyo urban area. The positioning was tried every second with the same units used in the experiment in Section 3. The experimental car drove in the Tokyo urban area.

Figure 9 and 10 show respectively an example of the horizontal positioning trajectory, and an example of the time series of the number of satellites with fixed ambiguity used for positioning while driving a car in the Tokyo urban area. The experimental car drove to the southern direction. It is confirmed that they can get the "Fix" solutions of network-based RTK-GPS by using FKP data transmission via ASC. But they often lose it, because the buildings block off the radio wave from the GPS satellites one after another while driving a car in the urban area. And it is natural that if the cycle slip of the carrier phase happens, initialization of the integer ambiguity is necessary. So it is earnestly desired the development of the method of "One epoch" integer ambiguity resolution to use RTK-GPS positioning under the condition of frequent blocking of the radio wave such as car driving in the urban area.

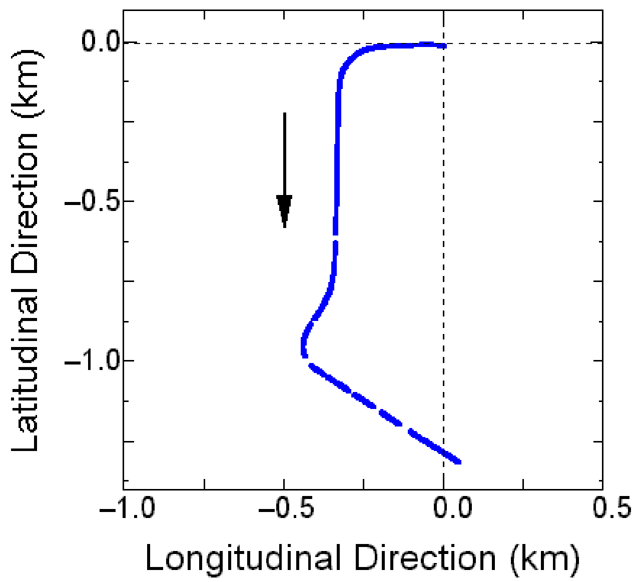

Figure 9 An Example of the Horizontal Positioning Trajectory While Driving a Car in the Tokyo Urban Area

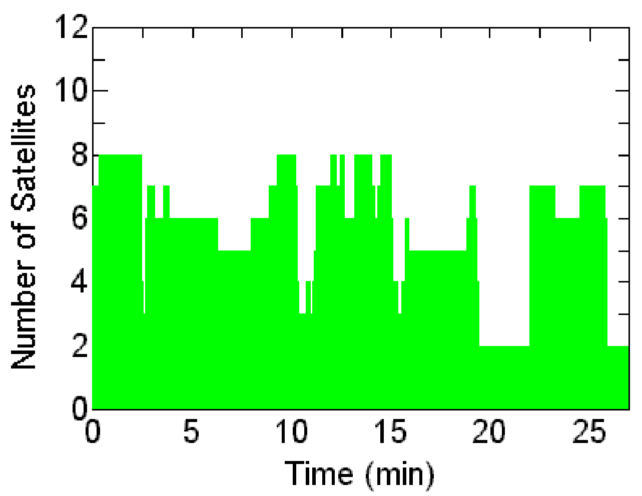

Figure 10 An Example of the Temporal Variation of the Number of Satellites with fixed ambiguity while Driving a Car in the Tokyo Urban Area

4.2 Positioning on a Sailing Boat

As another experiment on a running vehicle, RTK positioning with FKP data via ASC has been conducted on a sailing boat around the throat of Tokyo Bay. Originally established four reference stations are used. Three stations are allocated at the vertex of a triangle with three sides of about 70 km and the other one about 10 km off the center. We sailed around and made round trips 2 times with different distance around the center of the triangle. Figure 11 shows the outline of the route of boat. Although it takes a several minutes to fix when passing under some bridges, the fixed positions were available at the almost epochs on the whole. We also conducted the traditional RTK positioning as a reference, with baseline up to about 14km with the reference station in our campus. The results agreed well with each other.

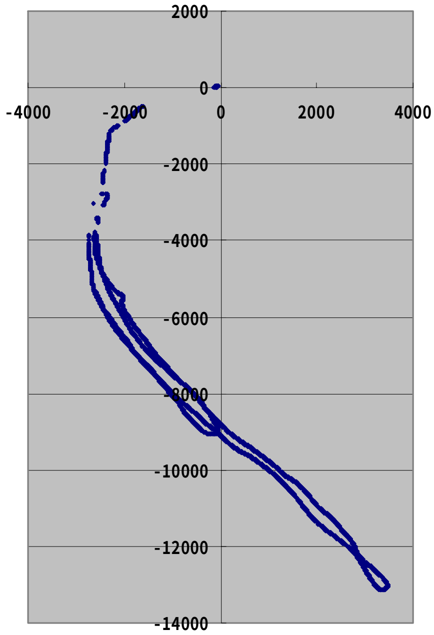

Figure 11 The result of RTK Positioning with FKP Data Acquired on a Sailing Boat in the Throat of Tokyo Bay. The Reference Station for the Traditional RTK Positioning is Located on the Origin of the Coodinates.

5. CONCLUSION

The authors investigated network-based RTK-GPS positioning using the area correction parameter, FKP via TV audio sub-carrier channel, ASC at a fixed point on the ground of the Tokyo University of Marine Science and Technology, located outside the network area. The site locates at the distance of 30 km from the main reference station, Ichihara, and outside the network area. The remarkable precision is obtained, however, in comparing to the traditional RTK-GPS positioning.

The values of 2drms of the horizontal distribution of the fixed positions are 2.95 cm by ASC and 3.14 cm by the public phone respectively. They are comparable to the traditional RTK-GPS under ordinary condition.

The authors also tried the network-based RTK-GPS positioning on a driving car in the Tokyo urban area by using FKP data transmitted by ASC.

The positioning data were acquired every second with the same unit at a fixed point. It is confirmed that the “Fix” solutions were available of network-based RTK-GPS by using FKP data. But they often failed, because the buildings block off the radio wave from the satellites one after another on a driving car in the urban area. Whenever the cycle slip of the carrier phase is detected, the initializing the integer ambiguity is required. The limited number of the satellites makes it difficult to resolve the ambiguity smoothly in the urban area. The positioning on a sailing boat is rather easier under the obstacle free environment. It is conducted with originally established reference stations. The continuously fixed positions were available with a middle range baseline positioning comparably accurate to those obtained by the traditional RTK-GPS positioning.

It is expected that the service areas will enlarge. The authors hope that the present experiment will help to promote the practical use of network-based RTK-GPS positioning system in Japan. We must improve the RTK-GPS precise positioning so as to be used easily.

ACKNOWLEDGMENTS

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