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The Comparison and Analysis of Maritime Precise Positioning using GPS Based Smartphone

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ABSTRACT

According to the Korea Coast Guard's maritime disaster statistics (Korea Coast Guard 2017, Korean Statistical information Service 2018), an average of 2,140 marine accidents occurred every year for the past 6 years and the number of accidents is increasing every year. Among them, maritime accidents of fishing vessels are the most frequent, and recently accidents involving fishing boat and leisure vessels are rapidly increasing as well. In particular, the number of accidents involving leisure vessels increased to about one-third of the accidents of fishing vessels, and emergency rescue requests are increasing every year accordingly. However, the number of crash accidents involving users of small vessels and marine leisure activities are increasing because of the difficulties of installing navigation equipment and electronic navigation charts. Recently, the demand for precise positioning using mobile devices is increasing in the fields of maritime safety, piloting support, and coastal survey. Although various applications of smart devices provide location-based services for users, the measurement results are discontinuous when using the position coordinates of the National Marine Electronics Association (NMEA) calculated by smartphone. Recently, Google announced that they will provide GPS raw data to developers from Android 7.0 Nougat. As a result, developers have an opportunity to receive precise carrier phase and code measurements to make more accurate positioning according to the performance of Android devices. This study analyzed GPS positioning performance using Android devices, and compared and analyzed the positioning performance at sea with high-performance GPS receivers.

Keywords: smartphone, android positioning, android carrier phase measurement, maritime precise positioning

1. INTRODUCTION

Recently, the market for maritime location-based services is expanding year after year. In particular, the marine GNSS market for small and leisure vessels is rapidly increasing every year and their market share is increasing as well (Fig. 1). Although GNSS market is growing due to the increase of leisure vessels around the world, accidents are also increasing because of the difficulties of installing precise navigation equipment. According to the Korea Coast Guard's maritime disaster statistics(Korea Coast Guard 2017, Korean Statistical information Service 2018), an average of 2,140 marine accidents occurred every year from 2012 to 2017 and the number of accidents is increasing year after year (Fig. 2). Although

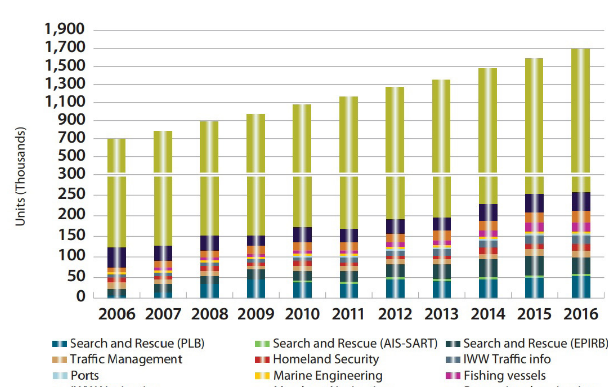

Fig. 1. GNSS unit shipments by application (GSA GNSS market report 2017).

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Fig. 2. Vessels accidents depending on the type.

maritime accidents of fishing vessels are the most common, the number of accidents involving fishing boat and leisure vessels has increased rapidly each year. In particular, the number of accidents involving leisure vessels increased to about one-third of the accidents of fishing vessels. However, it is difficult to prevent collisions and request emergency rescue because of the difficulties of installing navigation equipment and electronic navigation charts in small and leisure vessels in Korea. In addition to maritime accidents, the demand for precise navigation and positioning using mobile devices is increasing in the fields of piloting support and coastal survey. Although various applications of smart devices provide location-based services for the various needs of users, the measurement results do not guarantee continuity in dynamic environments, and it is difficult to apply various correction information and position performance algorithms in the location area.

Recently, Google announced that they will provide GPS raw data to developers from Android 7.0 Nougat. As a result, developers have an opportunity to receive precise carrier phase and code measurements to make more accurate positioning according to the performance of Android devices. Riley et al. (2017) compared the performance of Trimble's Catalyst mobile platform and Android devices to compare geodetic systems using Android devices. As a result, the study confirmed that cycle slips frequently occurred when using the signal-to-noise ratio and carrier phase measurements according to the type of smart devices, and also confirmed that the accuracy of GPS-alone horizontal positioning is within 10 m. Banville & van Diggelen (2016) analyzed Android-based raw data and discovered that the characteristics of device reduced the performance when the device is held in one's hands. In addition, the study confirmed that the position accuracy was within 10 m when using only code measurements, and within 5 m when using Doppler measurements. Navarro-Gallardo et al. (2017) compared the navigation performance including Galileo satellite, and Realini et al. (2017) compared the precision positioning performance using low-cost smart devices. Recently, comparative analysis studies and research on various platforms have been performed since 2017 based on Android devices. In particular, most of the studies were based on land and air platforms, and were focused on carrier-based relative positioning techniques.

This paper analyzed maritime positioning performance using Android devices at sea. Chapter 2 analyzed the characteristics of satellite signals of Android devices, Chapter 3 compared the results of stand-alone and precision positioning, and Chapter 4 analyzed the experimental results at sea.

2. ANDROID SATELLITE SIGNAL CHARACTERISTICS

Currently, devices with Android 7.0 or higher provide Pseudo-range, Navigation message, Accumulated delta range, and Hardware clock information to developers. Table 1 is a list of GNSS raw data currently available on Android devices (Google Developer 2018).

In this paper, we used a Samsung S9 smartphone to analyze Android-based raw data, and the device was installed as shown in Fig. 3 to collect constant raw data for 2 hours on October 11, 2018, using Google's GNSS Logger application.

In this paper, we used NovAtel's DL-V3 high-performance receiver to compare the characteristics of Android-based raw data. Figs. 4 and 5 compares the signal-to-noise ratio of the high-performance receiver and Android device. Fig. 4 shows the signal-to-noise ratio over time, where the High-performance receiver shows a range from 40 dB-Hz to 52 dB-Hz, while the Android device shows a range from 30 DB-Hz

Table 1. Specific device support raw GNSS measurements (GLO: GLONASS, GAL: GALLILEO, BD: BEIDOU, QZ: QZSS).

Model	Android version	Navigation message	Accumulated delta range	HW clock	Global systems
Huawei mate 10 Pro	8.0	yes	yes	yes	GPS, GLO
Google pixel 2	8.0	no	no	yes	GPS, GLO,GAL, BD, QZ
Samsung note 8	7.1	yes	yes	yes	GPS, GLO, GAL, BD
Samsung S8	7.0	yes	yes	yes	GPS, GLO, GAL, BD, QZ
LG V30	7.1.2	no	no	yes	GPS, GLO
Hauwei P10	7.0	yes	yes	yes	GPS, GLO, GAL, BD, QZ
Nexus 9	7.1	yes	yes	yes	GPS, GLO

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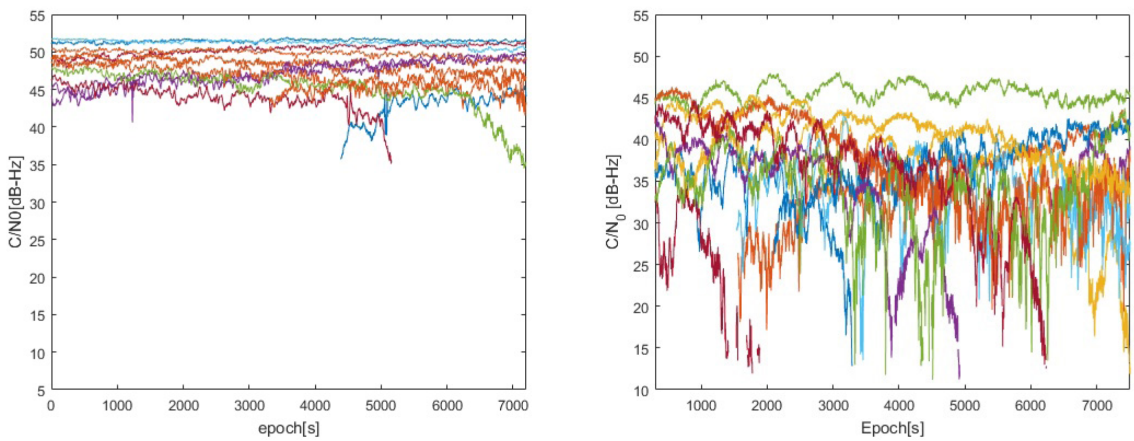
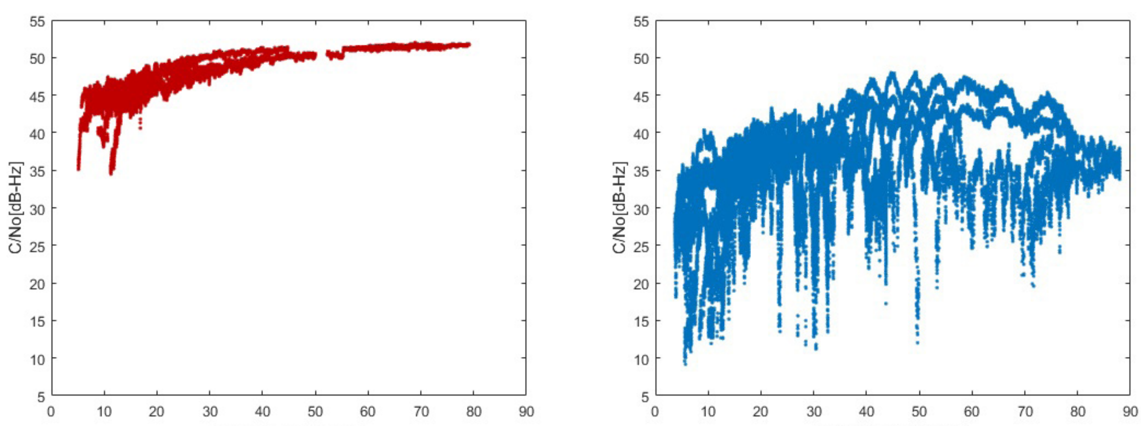
Fig. 3. Experimental setup.



(a) (b)

Fig. 4. Novatel and android C/N0. (a) NovAtel (b) Android



(a) (b)

Fig. 5. Novatel and android C/No versus elevation angle. (a) NovAtel (b) Android

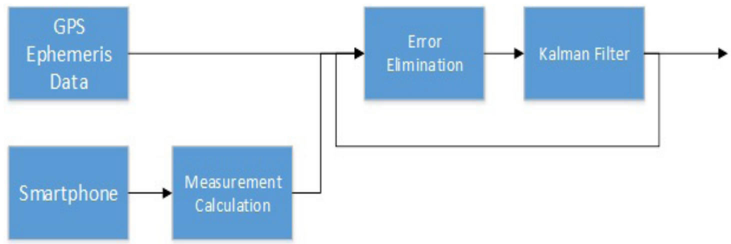


Fig. 6. Positioning algorithm block diagram.

to 47 dB-Hz, and shows a significantly lower signal-to-noise ratio than the high-performance receiver. Fig. 5 shows the signal-to-noise ratio according to elevation angle, where the signal-to-noise ratio of the Android device was not good even the elevation angle was high. The high-performance receiver showed higher signal-to-noise ratios as the elevation angle increased and lower ratios as the elevation angle decreased, and there was no significant difference in the signal-to-noise ratio at the same elevation angle. However, the Android device showed a high signal-to-noise ratio as the elevation angle decreased. This is caused by the poor antenna performance of Android device because it is vulnerable to multipath, and presents a large error in measurement noise. The data collected in this paper showed a low signal-to-noise ratio despite the high elevation angle, which is expected to affect the navigation performance. This is the data characteristics according to a specific date and surrounding environment, and because Android device is exposed to a high-level of multipath and noise, the location performance is significantly reduced and noise must be removed through various methods.

3. POINT POSITIONING ANLAYSIS

Android does not provide pseudo-range directly to developers as raw measurements, so the satellite signal transmission time and user signal received time needs to be calculated based on the raw measurements provided. The received time can be calculated using TimeNaNos, TimeOffsetNanos, FullGiasNonos, BiasNanos, and WeekNumberNonos provided by Android device. The WeekNumber can be calculated as shown in Eq. (1), and the reception time as shown in Eq. (2).

$$weekNumber = floor\left(-double\left(gnssRaw.FullBiasNonos\right)*1e-9 / GpsCons\tan ts.WEEKSEC\right) \quad (1)$$

$$Rxtime = \left(TimeNonos + TimeOffsetNanos\right) - \left(FullBiasNanos + BiasNonos\right) - WeekNumberNanos \quad (2)$$

In order to compare GPS positioning performance using Android devices, this study performed stand-alone positioning, DGPS positioning, carrier-based positioning, and carrier-based relative positioning between Android devices. The experiment was performed as shown in Fig. 3 by installing a Samsung S9 smartphone to collect data at a distance of about 30 cm between two devices. As shown in Fig. 6, positioning algorithm calculated the position solution by receiving the satellite orbit information and removing the errors. In the Stand-alone case, the errors were removed using Klobuchar model for the ionospheric delay, Saastamoinen model and Global Mapping Function for the troposphere delay, and DGPS correction information was used for the DGPS case. In the code-based positioning algorithm, the state variables of the Kalman filter were designed with the position and receiver clock errors as shown in Eq. (3).

$$\mathbf{x} = \begin{bmatrix} x & y & z & dt \end{bmatrix} \quad (3)$$

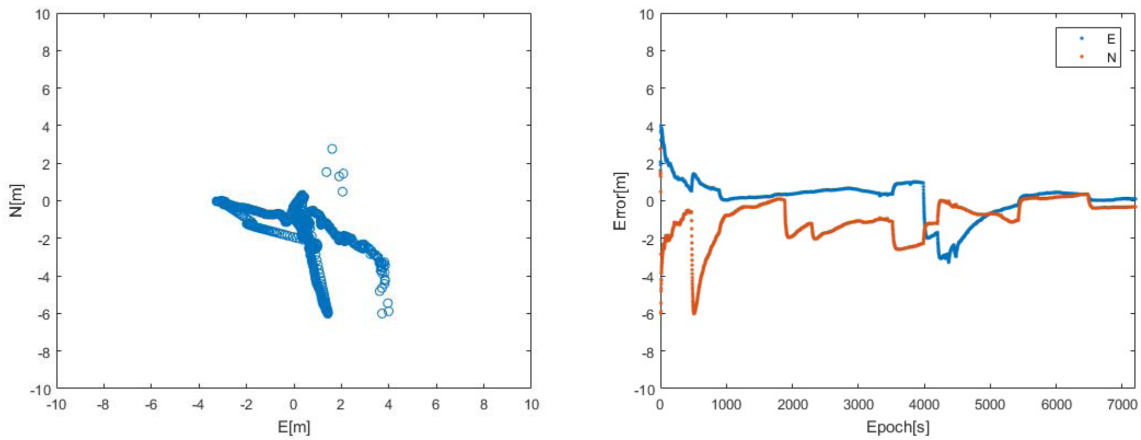
In the case of stand-alone positioning by carrier-based positioning algorithm, the ionospheric and tropospheric errors were removed as in the case based on code, and the state variables of the Kalman filter were designed with the position, float ambiguity, and receiver clock error as shown in Eq. (4).

$$\mathbf{x} = \begin{bmatrix} x & y & z & N_1 & N_2 & \cdots & N_m & dt \end{bmatrix} \quad (4)$$

In the case of carrier-based relative positioning, the errors were removed by the difference between the two receivers and the difference between the satellites, and the position solution was calculated by epoch-by-epoch signal processing the float ambiguity using the least squares method. In order to compare the performance of each algorithm, this study used data of elevation angles over 15 degrees and did not apply smoothing in consideration of the elevation contrast signal-to-noise ratio of Android devices as shown in Fig. 5.

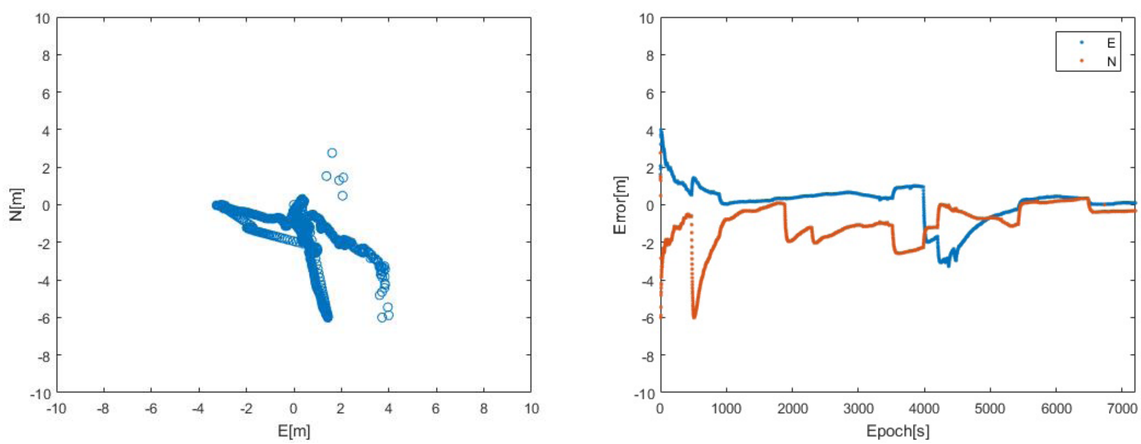
3.1 GPS Stand-alone Positioning Results

The GPS stand-alone positioning results based on the smartphone code measurements are as shown in Fig. 7.



(a) (b)

Fig. 7. Stand-alone horizontal results. (a) Horizontal error, (b) Positioning error in the East and North components, respectively.



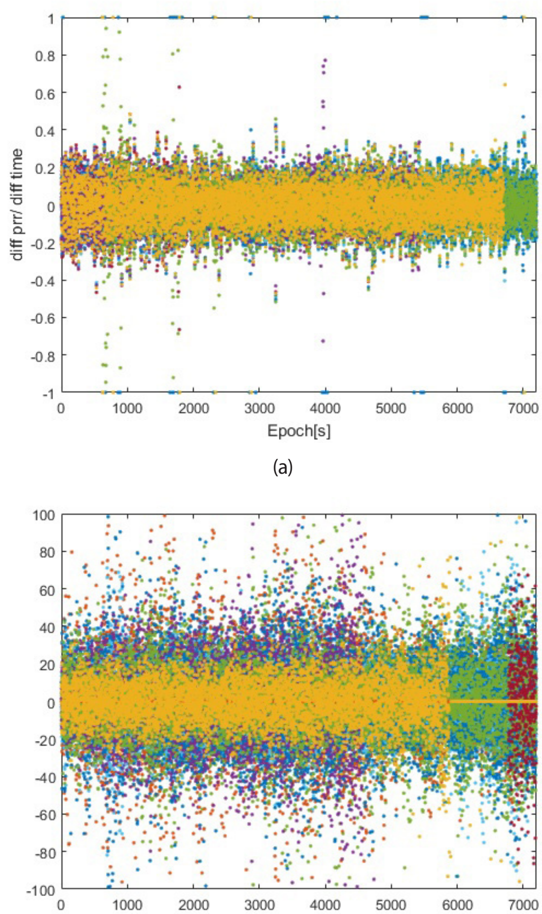
(a) (b)

Fig. 8. DGPS horizontal results. (a) Horizontal error, (b) Positioning error in the East and North components, respectively.

Fig. 7a shows the horizontal positioning results, and Fig. 7b shows the horizontal error results over time. The bouncing of the position values in Fig. 7b is considered to be the result of increased errors of the measured values due to the influence of rapidly decreasing signal-to-noise ratio, which affects the positioning accuracy. The horizontal positioning RMS was 1.81 m, which was more than 5 times the error of the horizontal positioning RMS of 0.38 m based on the NovAtel receiver, but the results were within 2 m. This is similar to the study results of Gim & Park (2017), and improved results can be obtained compared to National Marine Electronics Association (NMEA) values which are calculated by conventional smartphones.

3.2 DGPS Positioning Results

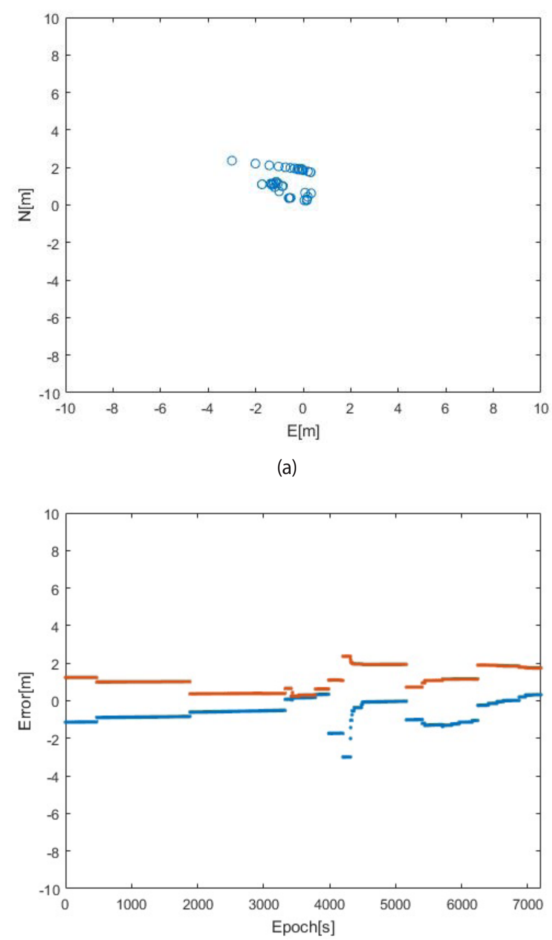
In order to confirm smartphone-based DGPS positioning performance, DGPS correction information data of Daejeon reference station was received through NTRIP. Fig. 8 shows the smartphone-based DGPS positioning performance results, where the horizontal positioning RMS was 1.74 m, which is a 10% improvement over code-based stand-alone positioning. However, in terms of using DGPS correction information, the position accuracy did not improve significantly compared to using a precision receiver. This is considered to be the result of significantly larger measurement noise errors than the ionospheric and tropospheric errors in GPS stand-alone case, resulting in less impact. Fig. 9 shows the time difference of the code measurement change ratio as the acceleration change rate of code measurement. Fig. 9a shows the results of NovAtel's high-performance receiver which do not exceed ±0.2 m/s2. On the other hand, Fig. 9b shows the results of Android device which show 100 times the error compared to Fig. 9a. Fig. 10 shows the residual of Android device measurement without the satellite clock, receiver clock, tropospheric error, and ionospheric error. When



(a)

(b)

Fig. 9. Code measurement 4th difference value. (a) NovAtel receiver, (b) android device



(a)

(b)

Fig. 11. Carrier phase based positioning horizontal results. (a) Horizontal error, (b) Positioning error in the East and North components, respectively.

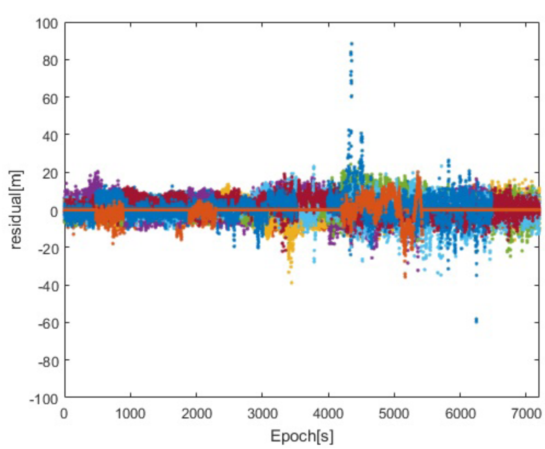
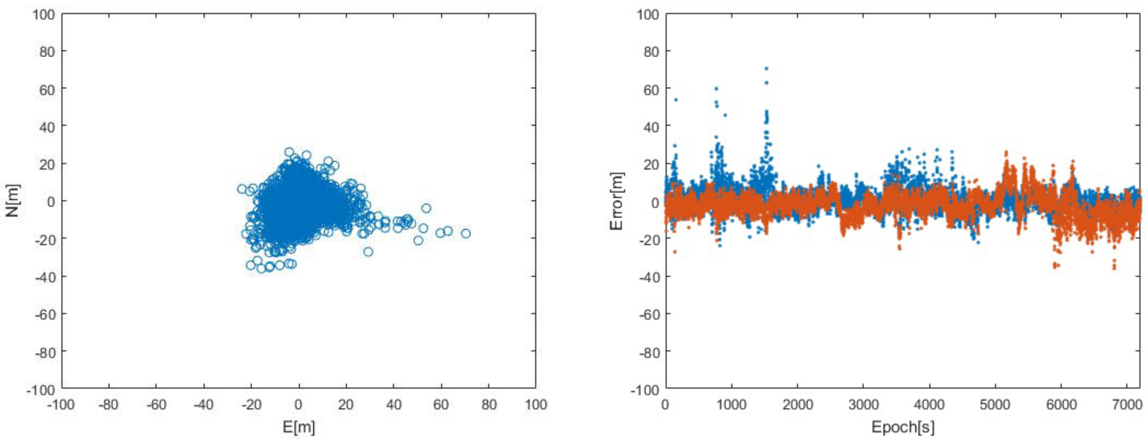


Fig. 10. Android Residual value.

DGPS correction information was applied within 20 m of the residual value, there was no performance improvement over the stand-alone positioning because of the errors that could not be removed. When using DGPS correction information, apply smoothing or remove the errors that were not removed in Fig. 10 in order to stabilize the rate of change of measured values in Fig. 9b. In order to remove the measurement noise and other errors based on code measurements, Warnant et al. (2018) confirmed that the positioning performance improved to within 50 cm by using Broadcom's recently released dual frequency (L1 + L5) chip, and in the case of GPS, the positioning performance showed errors in the range of 2 m-8 m according to the signal-to-noise ratio. Bellad & Marathe (2018) confirmed the improved positioning performance by receiving and processing precise GPS satellite information, and presented the use of Galileo signals in addition to GPS. Such methods can be used to improve the code-based stand-alone positioning and DGPS positioning performance.

3.3 GPS Carrier Phase Based Positioning Results

Recently, Android devices provide code measurements as well as carrier phase measurements according to the



(a) (b)

Fig. 12. Double difference positioning between two android device (a) Horizontal error, (b) Positioning error in the East and North components, respectively.

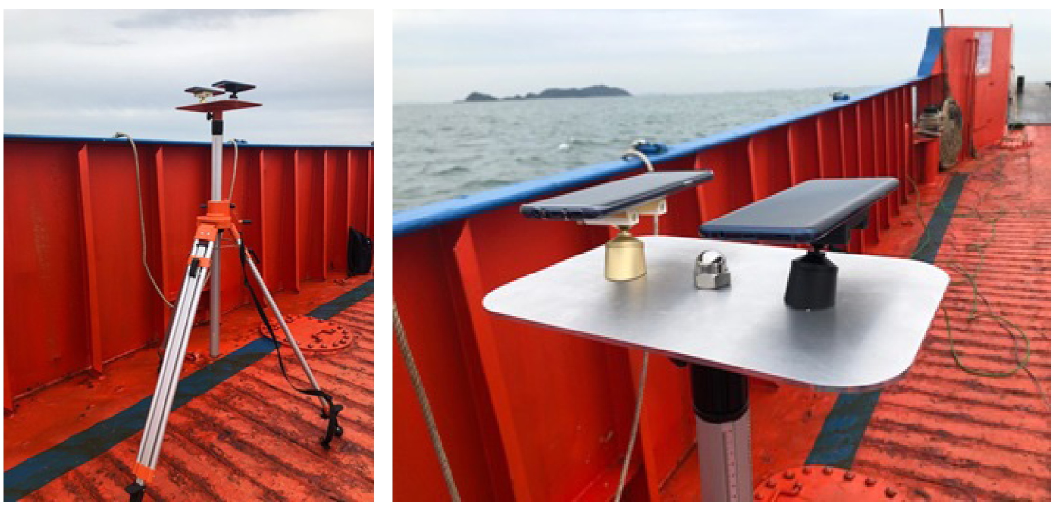
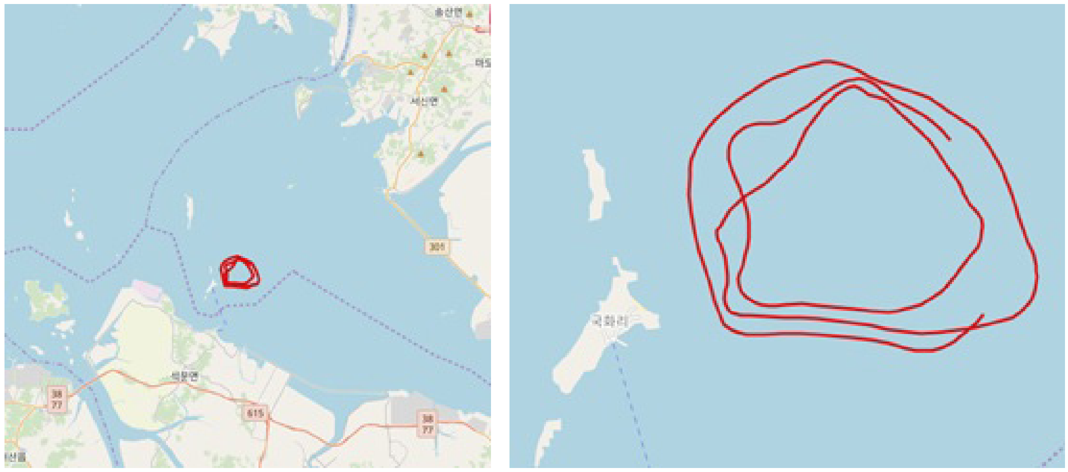


Fig. 13. Maritime experiment setup.

performance of the devices. The Android device tested in this paper also provides carrier phase measurements as shown in Table 1. For the positioning based on smartphone carrier phase measurements, this paper used the Kalman filter as shown in Eq. (4), and float ambiguity for each epoch was calculated. Fig. 11 shows GPS carrier-based positioning performance. Compared to Fig. 7, the accuracy was increased as the horizontal accuracy RMS was 3.31 m. This is a cycle slip problem caused by the duty cycle of Android devices, where convergence difficulties occur due to frequent cycle slips. These hardware clock interruptions may occur frequently depending on the type and time of Android device (Lu et al. 2018).

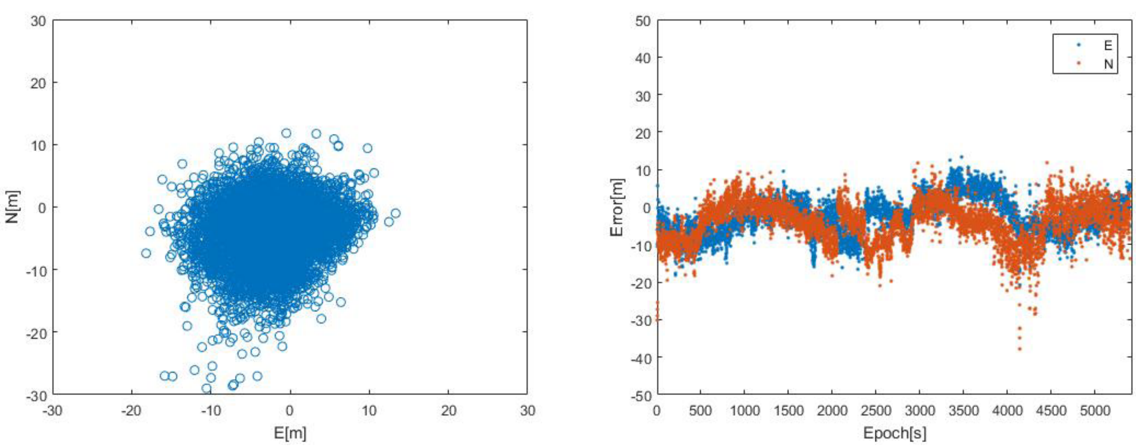
3.4 GPS Carrier Phase Based Double Difference Between Two Smartphones

As the correction information of the carrier phase measurements will not remove errors just like the case with DGPS for information generated by high-performance receivers, in order to analyze the relative positioning performance between Android devices, as shown in Fig. 3, this paper installed the same smartphone models on both sides of the surface plate as reference and rover receiver, and the carrier phase-based double difference relative positioning was calculated as a float solution using the data received from the two installed Android devices. The baseline was determined to be 30 cm, which is the length of the surface plate, by installing the devices at the edge of each surface plate according to the antenna direction of the smartphone. Fig. 12 shows the carrier phase-based double differential relative positioning results, where the error values are larger than the carrier phase stand-alone positioning results in Fig. 11. By using different filters from Fig. 11, the positioning error increased due to the error caused by the measurement noise



(a) (b)

Fig. 14. Maritime experiment trajectory.



(a) (b)

Fig. 15. Maritime experiment results (a) Horizontal error, (b) Positioning error in the East and North components, respectively.

of the two Android devices.

4. MARITIME POSITIONING RESULTS

4.1 Maritime Experimental Setup

Based on the experiment results under stationary conditions, this study performed an experiment near Pyeongtaek Port on September 13, 2018 to confirm the navigation performance using Android code raw data at sea. In order to receive the highest possible satellite signal-to-noise ratio, as shown in Fig. 13, we installed a surface plate and Android device on a vessel to collect the data. As shown in Fig. 14, the vessel test was performed for about 90 minutes near Gukhwa Island in the West Sea. Precision coordinates using VRS was applied to analyze the performance. At this time, the VRS antenna was installed approximately 5 m away from the Android device. Due to the experimental environment, we could not obtain the accurate coordinates of the Android device but we were able to estimate the coordinates by the horizontal error with VRS precision coordinates.

4.2 Maritime Positioning Results

The Android-based raw data collected at sea were calculated through post-processing using the Kalman filter. Fig. 15 shows the results of code measurement-based GPS stand-alone navigation, where RMS horizontal error was 8.6 m. Fig. 15b shows the position errors without considering VRS and lever arm, which are approximately within 10

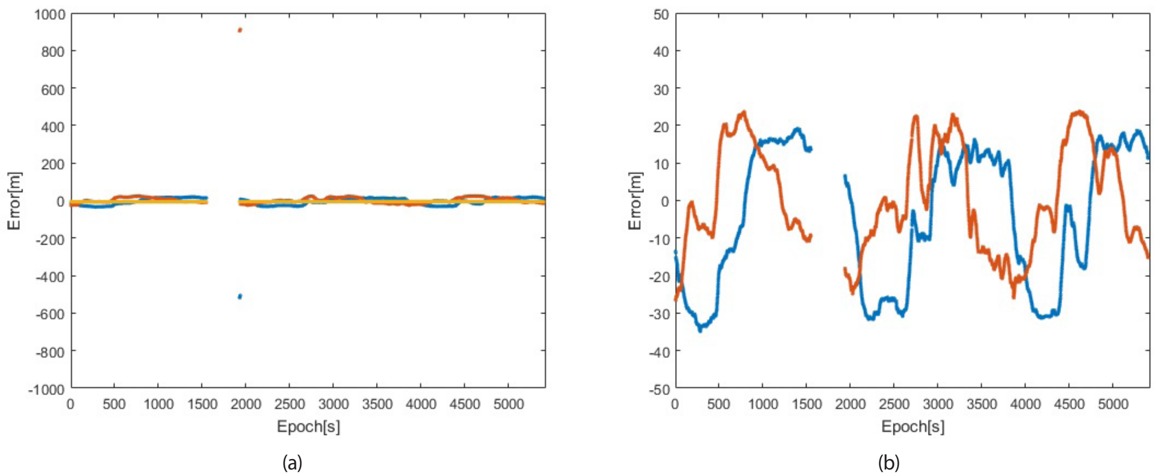


Fig. 16. Maritime experiment NMEA position error in the East and North components, respectively.

m. Considering the distance from VRS, we can expect a performance within RMS 5 m. Fig. 16 shows NMEA and VRS errors calculated from the Android device. Some sections are discontinuous followed by large errors, and the position accuracy shows a large value compared to Fig. 16b. Through this process, this study confirmed that the positioning results using GPS raw data in the marine environment are better than NMEA.

5. CONCLUSIONS

Recently, accidents involving small boats and leisure vessels are increasing rapidly in the ocean. Therefore, the need for navigation equipment in small vessels is emerging. Recently, Google started to provide developers with GPS raw data including carrier phase and code measurements on Android devices, which helps to determine the precise location. This paper analyzed the satellite signal characteristics of Android devices in order to analyze maritime precision positioning performance using Android devices at sea. This study analyzed GPS code and carrier-based stand-alone positioning performance as well. The code-based stand-alone positioning performance was RMS horizontal accuracy of 1.9 m and carrier-based stand-alone positioning performance was RMS 3.31 m. Problems such as cycle slips need to be considered for carrier measurements because of the hardware clock discontinuity. In terms of relative positioning, this study analyzed the code measurement correction information and the double difference relative performance between Android devices. In the case of relative positioning, there was no significant performance improvement than when using the correction information based on a high-performance receiver. This is because there is no significant impact on Android-based devices, which has large measurement noises. In addition, we confirmed the navigation performance of Android device through a marine experiment. The code-based GPS navigation results showed accuracy within 10 m compared to VRS location results, and showed a continuous and improved positioning performance than NMEA values. In future, we plan to analyze GPS stand-alone positioning performance to examine the relative positioning considering measurement noise reduction.

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