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GNSS user requirements for reuse development process considering pandemic

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***Abstract*---**Global Navigation Satellite System (GNSS) use the internal continuous reference times to evaluate a navigation solution, which includes U.S. GPS time, Russian GLONASS Time, the E.U. Galileo System Time, and Chinese Beidou time. GNSSs time are designed and configured to internally synchronize systems and evaluate navigation solution, and they are adjusted to synchronize their time into an external and stable reference clock. This paper analyzes and extracts requirements that are needed for designing components and design a component specification, which is based on the extracted components. From this study, common functions of GPS applications were constructed as a component. This method has advantages that can be assembled and reused. That is, it would develop a highly reliable method for software when common components are extracted from requirements for GNSS construction and component-based GNSS development process is achieved.

Keywords*---GNSS, specification, requirements.*

Introduction

Global Navigation Satellite System (GNSS) is a satellite-based navigation system. The system can locate itself at the place where it receives satellite signals. Global Positioning System (GPS) was developed by United States Department of Defense (DoD) for the military. And, with the development of technology, it is available for civilian use. GNSS is based on U.S. GPS, Russian GLONASS (Global Navigation Satellite System), and European Galileo, other satellite systems (Vikram et al., 2011; Pelgrum et al., 2011).

The GNSS receives electromagnetic waves transmitted from satellites and determines three-dimensional (3D) location on Earth. The location-based technologies are possible to determine a position at varying degree of accuracy, depending on user demand. As GNSS is based on the technologies, it has been miniaturized and improved with advancements in manufacturing technology of

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receivers and development in location algorithm. Due to these reasons, GNSS has been explosively expanded its ranges as extending location-based service such as drones and autonomous vehicles and other applications. Put differently, it is in the spotlight as an appropriate technology that can meet the needs for location information. The agencies operating GNSS are actively advancing and constructing their own independent system to lead the location-based service market utilizing location determination of a satellite (Gunawardena et al., 2008; Peng et al., 2010).

The basic principle of GNSS is to measure the propagation time which the time the signal takes to travel from a satellite to the receiver and calculate distance from a satellite to a receiver. Then, the current location of a user is determined by trigonometry. In these applications, it is significant that they are located on different domains, but they have common and key components. In other words, the existing applications have disadvantages in terms of separate implementation and development for each domain even though they have common components. Thus, from business-oriented viewpoint, GNSS applications extract key components, utilize them to build related applications, and improve software quality such as development, maintenance, productivity and so on. For effective extraction, in short, the GNSS components will have to be made of the self-execution unit that hierarchically modularizes functions for a system. By applying the reusable property, the components should be distinguished between reusable and new ones to reduce development time and secure quality components. To extract the quality ones, a systematic modeling method that accurately expresses users demand is required (Vikram et al., 2011; Humphreys et al., 2005; Xu et al., 2018).

The GPS applications developed so far separately construct their components for each domain though they have common functions in various domains. From the software engineering point of view, hence, it is a waste of time and expense. However, if common functions of GPS applications are constructed as a component, there would be advantages such as assembly and reuse. There will be various advantages in component-based development. To gain them, in this study, component-based GNSS development process will be defined, and COM components will be extracted by analyzing domains of DGPS- and IDGPS-related applications which are the technologies to correct GPS errors.

Related Works

Recently, in order to complete the system construction of Galileo in the EU (European Union) and BeiDou in China, satellite orbits have been arranged. Also, U.S. and Russia have been developing new satellites for advancement in GPS and GLONASS systems. Currently, as U.S., Russia, the EU, and China have started location determination services; users can receive signals from various systems at the same time, so a multi-GNSS location determination environment has truly constructed (Rino 2011; Jiao et al., 2017; Peng et al., 2014; Sang 2021).

In 1995, GPS reached the FOC (Full Operational Capability), but there have been modernizations of satellites and satellite ground control systems due to the development in the location-based technologies and increase in demands since early 2000s. After launching BLOCK IIR-M, the first modern satellite in 2005, there has been a constant updating in satellite functions such as development and arrangement of BLOCK IIF and BLOCK III satellites.

The design life of GPS Block-IIR-M, a kind of satellites, was improved to about eight years by adding new civilian signals (L2C) which are possible to tune carrier waves (L2), including legacy satellite signals. Block-IIF that has arranged its orbits since 2010 transmits all signals of earlier models, new carrier waves (L5), and code signals, and its design life was improved to 12 years. Block-III model that has arranged its orbits since 2018 sends the fourth civilian signal (L1C) which is possible to tune L1, and its design life was improved to 15 years. Also, its selective availability (SA) function was completely removed. Especially, as L5 and L1C are designed to share signals and frequency bands of other systems, it is to secure inter-operability.

The GLONASS is a satellite system to operate and maintain signals in Russian space forces, and its signal transmission method is frequency division multiple access (FDMA). Hence, it has low inter-operability with other GNSS systems using code division multiple access (CDMA) modulation. In 2003, Russia started GLONASS-M, the first generation of modern satellites, by recovering GLONASS system and conducting a modernization project. GLONASS-M, an initial model of modernized satellites, has a 0.1pm-level onboard clock and transmits the second civilian signal (L2OF) by tuning G2 carrier wave. GLONASS-K1, the second generation of modern satellites, has a 0.01pm-level onboard clock. Particularly, it transmits the third civilian signal (L3OC) by using CDMA modulation method to secure inter-operability with other GNSSs.

Galileo is one of GNSS, which is being developed in European space forces for civilian users. With GIOVE-A and -B satellites launched in 2005 and 2008, there have been initial tests such as satellite signal inspections and performance evaluations of satellite tracking and satellite ground control system. Using in-orbit validation (IOV), the fourth satellite, launched in 2011 and 2012, performances were evaluated for position and time. After then, 18 satellites were arranged in orbits by 2016 for providing services. Ultimately, the EU has a plan to declare FOC by arranging thirty satellites in orbits. Galileo system transmits four carrier waves (E1, E5a, E5b and E6) by modulating them through CDMA method.

Presently, there are GPS, GLONASS, Galileo, BeiDou, etc. that are kinds of GNSSs being provided across the world. In 1995, GPS reached the FOC (Full Operational Capability), but there have been modernizations of satellites and satellite ground control systems due to development in the location-based technologies and increase in demands since early 2000s. After launching BLOCK IIR-M, the first modern satellite, in 2005, there has been a constant updating in satellite functions such as development and arrangement of BLOCK IIF and BLOCK III satellites (Liu et al., 2019; Nam et al., 2018; Dharani 2019; Praveenkumar 2014).

GNSS System Analysis

The receiver of mobile station processes data with the signal from GPS satellite. That is, its own location information received from a satellite is extracted from

NMEA format, which is converted to WGS84 X, Y, Z coordinates for WGS84 latitude, longitude, and altitude. Then, the number GPS satellites and satellite IDs are collected, and satellite-related information is extracted to determine the location of each satellite.

Error Correction Algorithm. The reference station is possible to remove common errors of receivers of the reference station and users, which are satellite clock errors, ionospheric errors, and tropospheric errors. Satellite clock errors are calculated by information in navigation system messages converted to RTCM format not from the reference station, but the control station. The reference station generates pseudo range correction (PRC), Klobuchar model and Hopfield model are applied for ionospheric and tropospheric errors, respectively, to calculated errors.

Each Interface. The mobile station that has GPS receiver interface receives signals with NMEA format, a standard format, from GPS satellite. The station transmits processed data information through the network interface. The reference station sends correction values with RTCM format to the control station through the interface for other systems.

The mobile station that has GPS receiver interface receives signals with NMEA format, a standard format, from GPS satellite. The station transmits processed data information through the network interface. The reference station sends correction values with RTCM format to the control station through the interface for other systems.

Descriptive Specifications for Signal Reception. The mobile and reference stations must have a receiver, and the receiver of the mobile station must be able to receive signals from a satellite. Relatively, the receiver works accurately.

Table 1
Use case (descriptive) specification for signal reception

Use case	UC 1 Signals reception
Brief description	The mobile and reference stations receive signals with NMEA format, a standard format, from GPS satellite.
Actors	GPS satellite, receiver in mobile station, and reference station
Preconditions	The mobile and reference stations must have a receiver, and the receiver of the mobile station must be able to receive signals from a satellite. Relatively, the receiver works accurately.
Postconditions	Received NAME format information must be saved in DB.

Descriptive Specifications for Data Processing. Its own location information of signals received from a satellite is extracted with NMEA format, which is converted to WGS84 X, Y, Z coordinates for WGS84 latitude, longitude, and altitude. Then, the number of GPS satellite and satellite ID transmitted from NMEA format are extracted. Also, the satellite location is calculated by extracting satellite-related ephemeris information. The receiver extracts the time receiving signals from GPS satellite. Time is synchronized by adding nine hours to Universal Time Coordinated (UTC) received from NMEA format.

Table 2
Use case (descriptive) specification for data processing

Use case	UC2 Data processing
Brief description	The receiver in mobile station processes data with received signals.
Actors	Receiver in a mobile station
Preconditions	The messages received from a satellite must be NMEA format. The mobile and reference stations must have a receiver, and the receiver of the mobile station must be able to receive signals from a satellite. Relatively, the receiver works accurately.
Postconditions	Converted coordinates, the number of satellites and satellite ID, and calculated satellite location are saved in DB.

Descriptive Specifications for Data Transmission. It transmits its own location information (coordinates), the number of each satellite and satellite ID, the time received from a satellite, calculated satellite locations and other information.

Table 3
Use case (descriptive) specification for data transmission

Use case	UC3 Data transmission
Brief description	The mobile station transmits processed data information to the control station.
Actors	Receiver in mobile station and control station.
Preconditions	Converted coordinates, the number of satellites and satellite ID, and calculated satellite location must be saved in DB. The control station must have a receiver, and the receiver must be able to receive signals from a satellite. Its own location information of signals received from a satellite is extracted with NMEA format, which is converted to WGS84 X, Y, Z coordinates for WGS84 latitude, longitude, and altitude. Then, the number of GPS satellite and satellite ID transmitted from NMEA format are extracted. Also, the satellite location is calculated by

	extracting satellite-related ephemeris information. The receiver extracts the time receiving signals from GPS satellite. Time is synchronized by adding nine hours to Universal Time Coordinated (UTC) received from NMEA format
Postconditions	The mobile station must be able to transmit data information to the control station using wireless communication.

Descriptive Specifications for Error Calculation. When the reference station calculates errors, PRC is the ionospheric errors plus the tropospheric errors. To calculate the errors, Klobuchar model and Hopfield model are applied for ionospheric and tropospheric errors, respectively. When calculating errors with each algorithm, a receiver in reference station receives signals from a satellite. With the received information, errors will be calculated by the receiver using algorithm.

Table 4
Use case (descriptive) specification for error calculation

Use case	UC4 Errors calculation
Brief description	The reference station calculates errors.
Actors	The reference station
Preconditions	The reference must be able to receive signals from a satellite. Converted coordinates, the number of satellites and satellite ID, and calculated satellite location must be saved in DB. The control station must have a receiver, and the receiver must be able to receive signals from a satellite. It transmits its own location information (coordinates), the number of each satellite and satellite ID, the time received from a satellite, calculated satellite locations and other information
Postconditions	Each Calculated error value must be saved in DB.

Descriptive Specifications for Error Calculation → Transmission. The reference station configures error correction values, calculated error values, with RTCM format. The station transmits the information about errors to the control station.

Table 5
Use case (descriptive) specification for error transmission

Use case	UC 5 Error transmission
Brief description	The reference station transmits calculated error correction values with RTCM format to the control station.
Actors	Reference station and control station
Preconditions	The control station must be equipped with DGPS receiver that is able to receive RTCM format information. When the reference station calculates errors, PRC is the ionospheric errors plus the tropospheric errors. To calculate the errors, Klobuchar model and Hopfield model are applied for ionospheric and tropospheric errors, respectively. When calculating errors with each algorithm, a receiver in reference station receives signals from a satellite. With the received information, errors will be calculated by the receiver using algorithm.
Postconditions	The reference station must be able to transmit data information to the control station using wireless communication.

Descriptive Specifications for Satellite Clock Error Calculation. It calculates satellite clock errors by extracting error correction information with the navigation messages in RTCM format.

Table 6
Use case (descriptive) specification for satellite clock error calculation

Use case	UC6 Satellite clock error calculation
Brief description	The control station calculates satellite clock errors.
Actors	Control station
Preconditions	The control station must have RTCM format information received from the reference station. The reference station configures error correction values, calculated error values, with RTCM format. The station transmits the information about errors to the control station.
Postconditions	Calculated error correction values must be saved in DB.

Descriptive Specifications for Error Correction. The control station removes received ionospheric and tropospheric errors in RTCM format and calculated satellite clock error values from the PRC.

Table 7
Use case (descriptive) specification for error correction

Use case	UC 7 Error correction
Brief description	The control station corrects errors.
Actors	Control station
Preconditions	The control station must have RTCM format data received from the reference station and calculated satellite clock error correction values. It calculates satellite clock errors by extracting error correction information with the navigation messages in RTCM format.
Postconditions	PRC data without error values must be saved in DB.

Descriptive Specifications for Location Determination. To evaluate the most appropriate solution that satisfies the pseudo range equation using satellite location data received from the mobile station, linearization formula is created from non-linearization formula using the least square method and others, then locations and clock errors of a receiver are determined.

Table 8
Use case (descriptive) specification for location determination

Use case	UC 8 Location determination
Brief description	The control station determines the location of the mobile station receiver.
Actors	Control station
Preconditions	The values must already be corrected. The control station removes received ionospheric and tropospheric errors in RTCM format and calculated satellite clock error values from the PRC To evaluate the most appropriate solution that satisfies the pseudo range equation using satellite location data received from the mobile station, linearization formula is created from non-linearization formula using the least square method and others, then locations and clock errors of a receiver are determined.
Postconditions	The exact location of a receiver must be saved in DB.

GNSS Specification Technique

The hierarchical specifications of use case are as follows:

[UC 1 Signals reception]
[UC 1.1 The mobile and reference stations receive signals with NMEA format from GPS satellite]
[UC 2 Data processing]
[UC 2.1 The receiver in a mobile station extracts several data from NMEA format received from a satellite. Its own location information is converted to WGS84 X, Y, Z coordinates, and the satellite location is calculated by using ephemeris information of satellites.
[UC 2.1.1 Coordinate transformation]
[UC 2.1.1.1 The mobile station extracts its own location information with NMEA format, which is converted to WGS84 X, Y, Z coordinates for WGS84 latitude, longitude, and altitude.]
[UC 2.1.2 Extracting the number of GPS satellite]
[UC 2.1.2.1 The mobile station extracts the number of GPS satellite from NMEA format.]
[UC 2.1.3 Extracting GPS satellite ID]
[UC 2.1.3.1 The mobile station extracts the GPS satellite ID from NMEA format.]
[UC 2.1.4 Calculating GPS satellite location]
[UC 2.1.4.1 The mobile station calculates the satellite location by extracting ephemeris information from NMEA format.]
[UC 2.1.5 Extracting time]
[UC 2.1.5.1 The mobile station extracts time receiving signals from GPS satellite. Time is synchronized by adding nine hours to UTC received from NMEA format.]
[UC 3 Data transmission]
[UC 3.1 The mobile station transmits its own location information, satellite ID, the number of satellites, the time receiving signals from GPS satellite, and other information.]
[UC 3.1.1 Location information transmission]
[UC 3.1.1.1 The mobile station transmits its own location information to the control station.]
[UC 3.1.2 GPS Transmission of the number of satellites]
[UC 3.1.2.1 The mobile station transmits information about the number of satellites to the control station.]
[UC 3.1.3 GPS Satellite ID transmission]
[UC 3.1.3.1 The mobile station transmits information about GPS Satellite ID to the control station.]
[UC 3.1.4 Transmission of the time receiving signals]
[UC 3.1.4.1 The mobile station transmits information about the time receiving signals from GPS satellite to the control station.]
[UC 3.1.5 Satellite location information transmission]
[UC 3.1.5.1 The mobile station transmits information about GPS satellite location to the control station.]
[UC 4 Error calculation]
[UC 4.1 The reference station calculates ionospheric and tropospheric errors using Klobuchar Model and Hopfield Model, respectively.]
[UC 4.1.1 Calculating ionospheric errors]

[UC 4.1.1.1 Ionospheric errors are calculated by Klobuchar Model.]
[UC 4.1.2 Calculating tropospheric errors]
[UC 4.1.2.1 Tropospheric errors are calculated by Hopfield Model.]
[UC 4.1.3 Calculating PRC values]
[UC 4.1.3.1 PRC values are calculated by using the ionospheric and tropospheric errors.]
[UC 5. Error transmission]
[UC 5.1 The reference station transmits calculated error correction values with RTCM format to the control station.]
[UC 5.1.1 RTCM Correction information configuration]
[UC 5.1.1.1 The reference station configures the calculated error correction values in RTCM SC-104 format.]
[UC 5.1.2 RTCM Transmission of correction information]
[UC 5.1.2.1 The reference station transmits information about error correction values configured in RTCM SC-104 format to the control station.]
[UC 6. Satellite clock error calculation]
[UC 6.1 The control station calculates satellite clock errors.]
[UC 6.1.1 Extracting information about error correction values]
[UC 6.1.1.1 Error correction information is extracted from the information in navigation messages in RTCM format.]
[UC 6.1.2 Satellite clock error calculation]
[UC 6.1.2.1 It calculates satellite clock errors by using information about extracted error correction.]
[UC 7. Error correction]
[UC 7.1 The control station corrects ionospheric and tropospheric errors in RTCM format and calculated satellite clock errors.]
[UC 8. Location determination]
[UC 8.1 To evaluate the most appropriate solution that satisfies the pseudo range equation with data received from the mobile station, the control station calculates clock errors and locations of a receiver, using the least square method and others.]
[UC 8.1.1 Calculating clock errors of a receiver of mobile station]
[UC 8.1.1.1 The clock errors of a receiver are calculated by using data received from the control station.]
[UC 8.1.2 Calculating locations of a receiver of mobile station]
[UC 8.1.2.1 The solution that satisfies the pseud orange equation is evaluated with data received from the mobile station to determine the location of a receiver.]

Candidate component extraction is preceded as follows:

GPS Data Process. The receiver of mobile station processes data with the signal from GPS satellite.

(1) Its own location information received from a satellite is extracted from NMEA format, which is converted to WGS84 X, Y, Z coordinates for WGS84 latitude, longitude, and altitude.
-> Extracting candidate components for coordinate transformation.
(2) In NMEA format, the number GPS satellites and satellite IDs are collected, and satellite-related information is extracted to determine location of each satellite.

-> After extracting satellite-related information, extracting candidate components for satellite location calculation.

Error Correction Algorithm. The reference station is possible to remove common errors of receivers of reference station and users, which are satellite clock errors, ionospheric errors, and tropospheric errors. Internal noise and multipath errors that are irrelevant are impossible to correct. The reference station generates pseudo range correction (PRC) that is the ionospheric errors plus the tropospheric errors.

(1) Satellite clock errors are calculated not at the reference station, but the control station. It calculates satellite clock errors with the navigation messages in RTCM format.
-> Extracting candidate components for calculating satellite clock errors.
(2) Klobuchar model is applied for ionospheric errors to calculated errors.
-> Extracting candidate components for calculating ionospheric errors.
(3) Hopfield model algorithms are applied for tropospheric errors to calculated errors.
-> Extracting candidate components for calculating tropospheric errors.

Each Interface

(1) GPS receiver interface (mobile station and reference station)
The mobile station receives signals with NMEA format, a standard format, from GPS satellite.
(2) Network interface (mobile station)
The mobile station transmits processed data information to the control stations. It transmits information about its own location, satellite ID, the number of satellites, the time received from a satellite, and the GPS satellite location.
(3) Interface to other systems (reference station)
The reference station transmits calculated error correction values with RTCM format to the control station.
The receiver of mobile station processes data with the signal from GPS satellite.
(1) Its own location information received from a satellite is extracted from NMEA format, which is converted to WGS84 X, Y, Z coordinates for WGS84 latitude, longitude, and altitude.
(2) In NMEA format, the number of GPS satellites and satellite ID are collected, and satellite-related information is extracted to determine the location of each satellite.

Error Correction Algorithm. The reference station is possible to remove common errors of receivers of reference station and users, which are satellite clock errors, ionospheric errors, and tropospheric errors. Internal noise and multipath errors that are irrelevant are impossible to correct them.

The reference station generates pseudo range correction (PRC) that is the ionospheric errors plus the tropospheric errors. Satellite clock errors are calculated at not the reference station, but the control station.

(1) Klobuchar model is applied for ionospheric errors to calculated errors.
(2) Hopfield model algorithms are applied for tropospheric errors to calculated errors.
(3) It calculates satellite clock errors with the navigation messages in RTCM format.

Each Interface

(1) GPS receiver interface (mobile station and reference station)
The mobile station receives signals with NMEA format, a standard format, from GPS satellite.
(2) Network interface (mobile station)
The mobile station transmits processed data information to the control station. It transmits information about its own location, satellite ID, the number of satellites, the time received from a satellite, GPS satellite location.
(3) Interface to other systems (reference station)
The reference station transmits calculated error correction values with RTCM format to the control station.

Candidate component extraction is preceded as follows:

GPS Data Process. The receiver of mobile station processes data with the signal from GPS satellite.

(1) Its own location information received from a satellite is extracted from NMEA format, which is converted to WGS84 X, Y, Z coordinates for WGS84 latitude, longitude, and altitude.
-> Extracting candidate components for coordinate transformation.
(2) In NMEA format, the number GPS satellites and satellite ID are collected, and satellite-related information is extracted to determine location of each satellite.
-> After extracting satellite-related information, extracting candidate components for satellite location calculation.

Error Correction Algorithm. The reference station is possible to remove common errors of receivers of reference station and users, which are satellite clock errors, ionospheric errors, and tropospheric errors. Internal noise and multipath errors that are irrelevant are impossible to correct them. The reference station generates pseudo range correction (PRC) that is the ionospheric errors plus the tropospheric errors.

(1) Satellite clock errors are calculated at not the reference station, but the control station. It calculates satellite clock errors with the navigation messages in RTCM format.
-> Extracting candidate components for calculating satellite clock errors.
(2) Klobuchar model is applied for ionospheric errors to calculated errors.
-> Extracting candidate components for calculating ionospheric errors.

(3) Hopfield model algorithms are applied for tropospheric errors to calculated errors.
-> Extracting candidate components for calculating tropospheric errors.

Conclusions

With regard to diverse mobile communication services, there has been a growing demand for location-based service (LBS), and accuracy and reliability of location determination have continued to gain importance. According to the world's first requirements of accuracy and reliability of emergency rescue service of U.S. FCC in 1999, the network-based location determination has 100 m accuracy (67% of probability) and 300 m accuracy (95% probability). And, mobile-based location determination, including assisted global navigation satellite systems (A-GNSS) technology, has 50 m accuracy (67% probability) and 150 m accuracy (95% probability).

GNSSs use the internal continuous reference times to evaluate a navigation solution, which includes U.S. GPS time, Russian GLONASS Time, the E.U. Galileo System Time, Chinese Beidou time, etc. GNSSs time are designed and configured to internally synchronize systems and evaluate navigation solution, and they are adjusted to synchronize their time into an external and stable reference clock.

This study to analyzes and extracts requirements that are needed for designing components and designs a component specification, which is based on extracted components. From this study, common functions of GPS applications were constructed as a component. This method has advantages that can be assembled and reused. That is, it would develop a highly reliable method for software when common components are extracted from requirements for GNSS construction and a component-based GNSS development process is achieved.

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