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USER SEGMENT OF KOREAN WIDE AREA GLOBAL NAVIGATION SATELLITE SYSTEM

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ABSTRACT

Korean wide area differential global navigation satellite system augments global navigation satellite system by broadcasting additional signals from geostationary satellites and providing differential correction messages and integrity data for the GNSS satellites. It includes a network of wide area reference stations, wide area master station, ground earth station and geostationary satellites. Wide area reference stations are widely dispersed GNSS data collection sites that monitor and process satellite data to determine satellite orbit and clock drift plus delays caused by atmosphere and ionosphere. This information is then transmitted to wide area master station which creates and broadcasts correction messages through geostationary satellites. The user segment receives and applies correction messages to improve position accuracy and reliability. This study presents a flexible and robust software design and data processing algorithms of user segment of Korean wide area differential global navigation satellite system. The user segment software performs numerous functions such as calculation of ionosphere and troposphere delays, processing of correction messages, and data quality monitoring. It implements numerous tropospheric, ionospheric and position models, supports RINEX and BINEX data exchange formats, and is designed to work in real time and post processing modes. It can also be used in precision and non-precision approach modes. The software is divided into several layers such as Data Processing and Visualization, and can be easily extended to support various interfaces such as web interface and mobile device interface. The current version processes global positioning system and wide area differential global navigation satellite system data but can be easily extended to support various global navigation satellite systems such as GLONASS and Galileo.

Keywords: *Global Navigation Satellite System, Global Positioning Systems, GPS Augmentation System*

1. INTRODUCTION

Korean wide area differential global navigation satellite system is a large scale research project funded by Ministry of Land, Transport and Maritime Affairs [1]. It augments global navigation satellite system [4] by broadcasting additional signals from geostationary satellites and providing differential correction messages and integrity data for the GNSS satellites. It includes a network of wide area reference stations, wide area master station, ground earth station and geostationary satellites. Wide area reference stations are widely dispersed GNSS data collection sites that monitor and process satellite data to determine satellite orbit and clock drift plus delays caused by atmosphere and ionosphere. This information is then transmitted to wide area master station which creates and broadcasts correction messages through geostationary satellites. The user segment receives and applies correction messages to improve position accuracy and reliability [2].

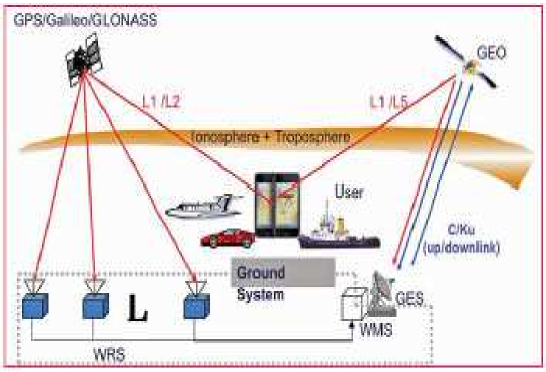

Figure 1: Korean WA-DGNSS Architecture

design and data processing algorithms of user

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segment of Korean wide area differential global navigation satellite system [3]. The user segment software performs numerous functions such as calculation of ionosphere and troposphere delays, processing of correction messages, and data quality monitoring. It implements numerous tropospheric, ionospheric and position models, supports RINEX and BINEX data exchange formats, and is designed to work in real time and post processing modes. It can also be used in precision and non-precision approach modes. In the precision approach mode, fast, slow, ionospheric and tropospheric corrections are applied while in the non-precision approach mode only fast and slow corrections are applied [4].

The software is divided into several layers such as Data Processing and Visualization, and can be easily extended to support various interfaces such as web interface and mobile device interface. The current version processes global positioning system and wide area differential global navigation satellite system data but can be easily extended to support various global navigation satellite systems such as GLONASS and Galileo [4].

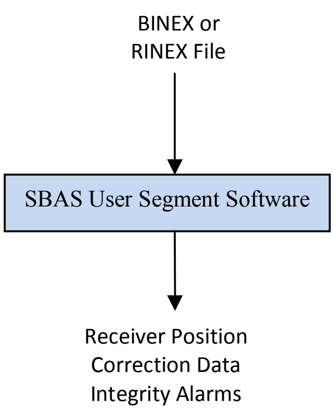

Figure 2: User Segment Software Block Diagram

2. ARCHITECTURAL DESIGN

Architecture of user segment software is given in Figure 3 which shows the relationship between key components. For a detailed description, readers are referred to [5].

3. DATA PROCESSING ALGORITHMS

Wide area master station broadcasts three types of correction messages through geostationary satellites. 1) Fast Corrections for satellite clock's rapid and short-term errors, 2) Slow Corrections for satellite clock's slow drift errors and slow ephemeris errors, and 3) Ionospheric Grid Point Corrections for the estimated ionosphere signal propagation delays [2]. A block diagram of corrections message processing is given in Figure 4. In this section, key algorithms required to process and apply fast and slow corrections messages are described. For a detailed description of data processing algorithms, readers are referred to [6].

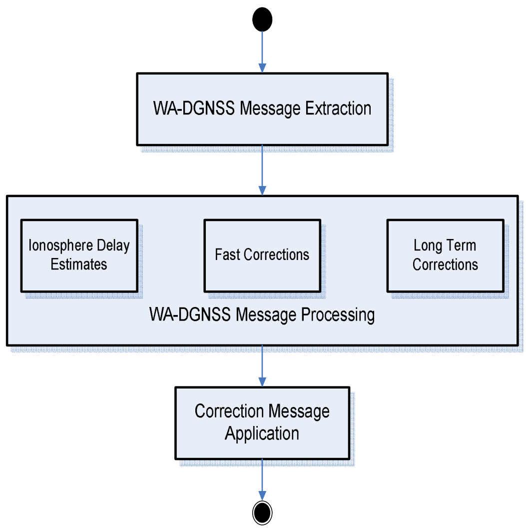

Figure 4: Corrections Message Processing Block Diagram

3.1 Processing of Fast Corrections

Fast corrections are used to correct fast-changing parameters such as satellite clock errors, and are included in message type 2-5 and 24. The fast corrections message contains pseudorange corrections and user differential range correction indicator. PRC is used to remove pseudorange error whereas UDREI is satellite health parameter which takes values in range of 1 to 15.

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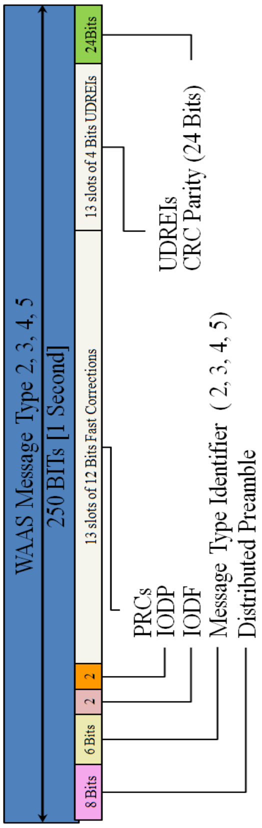

Figure 5: Fast Corrections Message Type 2-5

Algorithm for processing fast corrections is given below.

IF (MT == 0)
System Testing
IF (MT == 1)
Store PRN mask and IODP provided in MT 1
IF (MT == 2-5 || MT==24)
IF (IODP != IODP provided in MT 1)
Return
IF (UDREI == 14 || UDREI == 15)
Initialize RRC calculation
RRC = 0
Update satellite status
Return
IF (PRC is invalid) Return
IF (PA mode == true)
IF (UDREI>=12)
Satellite status = "do not use"
Return

IF (ai_i ==0)
RRC = 0
ELSE
Select $PRC_{previous}$
IF (IODF of $PRC_{current}$ == 3)
Select $PRC_{previous}$ which is closest to
$\frac{I_{fc}}{2}$ Seconds prior to the $PRC_{current}$

IF (IODF<3)
Select recently transmitted $PRC_{previous}$
Calculate range rate corrections using following equation:

$$RRC(t_{of}) = \frac{PRC_{current} - PRC_{previous}}{t_{of,current} - t_{of,previous}}$$

Calculate total range or fast corrections:
Check RRC status
IF (($t - t_{of}$) > I_{fc} ||
($t - t_{of} - 1$) > 8($t_{of} - t_{of,previous}$) ||
($t_{of} - t_{of,previous}$)> I_{fc})
Time-out
RRC status = invalid
ELSE
$FC(t) = PRC(t_{of}) + RRC(t_{of})(t - t_{of})$

IF (MT == 6)
IF ($IODF_j$ == 3)
IF (message is invalid)
Return
ELSE
Decode UDRE bounds
Apply UDRE bounds to corrections
Recalculate pseudorange & position solution

IF ($IODF_j$ < 3)
Match $IODF_j$ with $IODF_j$ provided in MT j (2-5 and 24)
IF (match==False) Return
IF (message is invalid) Return

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```
ELSE
  Decode UDRE bounds
  Apply UDRE bounds to corrections provided in
  MT j
  Recalculate pseudorange and position solution

IF (MT == 7)
  IF (IODP != IODP provided in MT 1)
    Return
ELSE
  Store the UDRE degradation and
  Time-out intervals
```

Table 1: Notations used in algorithm

Notation	Description
IODP	Issue of Data PRN
MT	Message Type
PA	Precision approach
NPA	Non precision approach
$PRC_{previous}$	Previously received pseudorange corrections
I_{fc}	Time-out interval for PRC
RRC	Range rate corrections
PRC	Pseudorange corrections
$t_{of,current}$	Time of applicability of the most recent received pseudorange correction.
$t_{of,previous}$	Time of applicability of the previously received pseudorange correction.
FC	Total fast correction
t	User time
t_{of}	Time of applicability of the most recent fast correction

3.2 Application of Fast and Slow Corrections

Fast corrections are used to correct fast-changing parameters whereas slow or long term corrections are used to provide error estimates for slow varying satellite ephemeris and clock errors, and are included in message type 24 and 25 [7]. The slow corrections message contains satellite position corrections, velocity corrections and satellite clock corrections. Message type 25 may be broadcast in two forms as per requirement. The Figure 6 shows the schematic of each form.

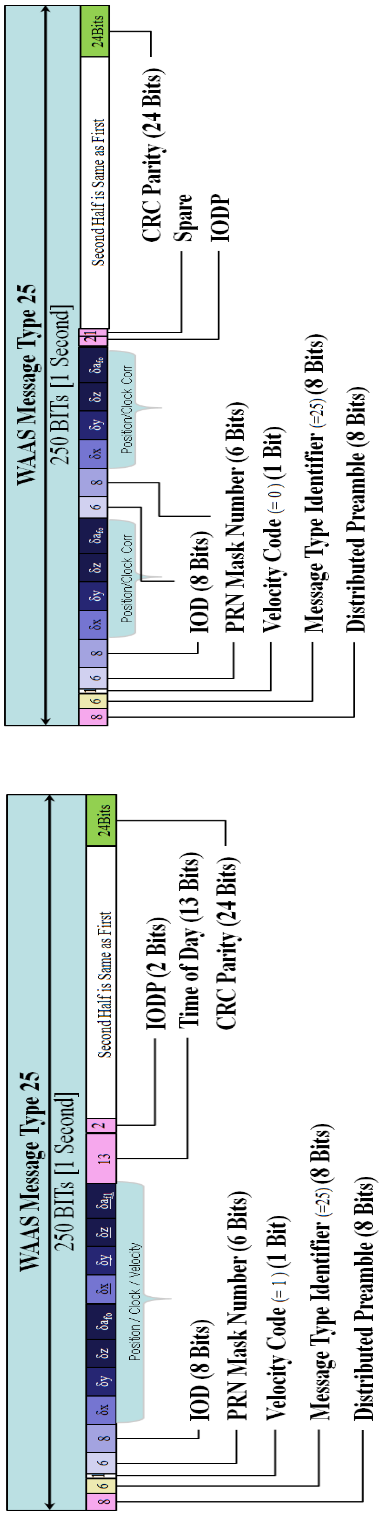

Figure 6: Slow Corrections Message Type 25

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The algorithm for application of correction messages is given below.

```
Check Integrity
IF (UDREI==15)
   Satellite = unhealthy

IF (UDREI==14 ||
    DGNSS data == invalid ||
    IOD! =IODE)
   Satellite = unmonitored

IF (PA mode == true)
     IF (UDREI in MT 2-5 & 24 >= 12)
         Satellite Status = Do not use
IF (PA mode==true)
     IF (Correction message is missed &
         Previously received correction data == valid)

       Apply degradation models
       Apply fast, ionospheric, tropospheric and
       clock corrections:
```

$$PR = PR_{measured} + FC - IC_{SBAS} + TC_{SBAS} + CC$$

Apply long term corrections:

$$\begin{bmatrix} x_{corrected} \\ y_{corrected} \\ z_{corrected} \end{bmatrix} = \begin{bmatrix} x_{GPS} \\ y_{GPS} \\ z_{GPS} \end{bmatrix} + \begin{bmatrix} \delta x \\ \delta y \\ \delta z \end{bmatrix}$$

```
IF (Correction messages are not missed &
    fast, slow, ionospheric & tropospheric
                  corrections are available)
        Apply fast, ionospheric, tropospheric and
        clock corrections:
```

$$PR = PR_{measured} + FC - IC_{SBAS} + TC_{SBAS} + CC$$

Apply long term corrections:

$$\begin{bmatrix} x_{corrected} \\ y_{corrected} \\ z_{corrected} \end{bmatrix} = \begin{bmatrix} x_{GPS} \\ y_{GPS} \\ z_{GPS} \end{bmatrix} + \begin{bmatrix} \delta x \\ \delta y \\ \delta z \end{bmatrix}$$

```
ELSE
    PA not possible
    Exit

IF (NPA mode == true)
    IF (Fast and slow corrections are available)
        Apply fast corrections:
```

$$PR = PR_{measured} + FC + CC$$

Apply slow corrections:

$$\begin{bmatrix} x_{corrected} \\ y_{corrected} \\ z_{corrected} \end{bmatrix} = \begin{bmatrix} x_{GPS} \\ y_{GPS} \\ z_{GPS} \end{bmatrix} + \begin{bmatrix} \delta x \\ \delta y \\ \delta z \end{bmatrix}$$

```
        IF (DGPS iono corrections are available)
            Apply DGPS ionospheric corrections:
```

$$PR = PR_{measured} + FC - IC_{SBAS} + CC$$

```
        ELSE IF (GPS iono corrections available)
                Apply GPS ionospheric corrections:
```

$$PR = PR_{measured} + FC - IC_{GPS} + CC$$

```
        ELSE
              Do not apply ionospheric corrections

        IF (DGPS tropo corrections are available)
             Apply DGPS tropospheric corrections:
```

$$PR = PR_{measured} + FC - IC_{SBAS} + TC_{SBAS} + CC$$

```
        ELSE
                Do not apply tropo corrections
    ELSE
        Do not use the satellite
```

3.3 Calculation of Pseudorange Residual

Pseudorange residual implies the remaining error obtained after eliminating errors such as satellite clock bias, ionospheric delay, tropospheric delay, and clock error from the smoothed pseudorange of satellite j. An algorithm to calculate pseudorange residual is given below.

a) Calculate Distance between Reference Station and Satellite j

$$D_j = \sqrt{(x - x_j)^2 + (y - y_j)^2 + (z - z_j)^2}$$

(x, y, z) Reference Station Coordinates

(x_j, y_j, z_j) Satellite j Coordinates,

Satellite ephemeris error is included

b) Calculate Pseudorange

$$PR_j = D_j + d_{iono} + d_{tropo} - \Delta t_{sv} + B + e_p$$

e_p Measurement noise

B is receiver clock error

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c) Smooth Pseudorange

Pseudorange $p1_k$, $p2_k$ of satellite j is available from the navigation message.

Smoothed pseudorange is obtained by

$$\widehat{\rho 1}_k = \frac{K-1}{K}[\widehat{\rho 1}_k + \Delta\Phi 1_k - \frac{2}{\gamma-1}\Delta(d\Phi_k)] + \frac{1}{K}\rho 1_k$$

$$\widehat{\rho 2}_k = \frac{K-1}{K}[\widehat{\rho 2}_k + \Delta\Phi 2_k - \frac{2\gamma}{\gamma-1}\Delta(d\Phi_k)] + \frac{1}{K}\rho 2_k$$

$$d\phi_k \equiv \phi 2_k - \phi 1_k$$

$$\triangle(d\phi_k) = d\phi_k - d\phi_{k-1} = \triangle\phi 2_k - \triangle\phi 1_k$$

$$\triangle\Phi_k = \Phi_k - \Phi_{k-1}$$

K: Averaging smoothing constant, K=300

k: Epoch

d) Calculate Pseudorange Residuals

$$PRR_j = SPR_j - D_j - d_{iono} - d_{tropo} + \Delta t_{sv} - B$$

4. CLASS DIAGRAMS

Class diagram is used to model the static view of a system. It includes classes, their attributes, operations and relationships with other classes [8]. Rectangles are used to represent classes.

.

The most important classes of user segment software of Korean wide area differential global navigation satellite system are shown in Figure 7. The classes are divided into five groups, each represented with a different color. The classes in light green color are used to represent raw and preprocessed data whereas classes in light purple color are used to represent fast and slow corrections data. Classes in sky blue and orange colors are data processing classes that are used to process raw global positioning system data and wide area differential global navigation satellite system correction messages, respectively. The classes in tan color are used to parse RINEX navigation and observation files and BINEX files. For a detailed description of each class, readers are referred to [5].

5. SOFTWARE MODULES

User Segment software provides an interface to access numerous modules in real time and post processing modes. The key modules of user segment software are briefly described below.

Data Handlers

Data Handlers are used to hold raw and pre-processed data during the execution. Some classes such as RawPre-proccssedDataBuffer, GlobalData and Time are used to buffer raw and preprocessed data for further processing and provide utility functions to convert between time standards and coordinate systems.

Data Processor

Data Processor is used to process raw data. The raw data is accessed from data handler classes and after processing either is made available to user interface classes for display or transmitted across the network. Numerous tropospheric, ionospheric and position models are implemented in this module. The diagram of data processing classes is given in Figure 8.

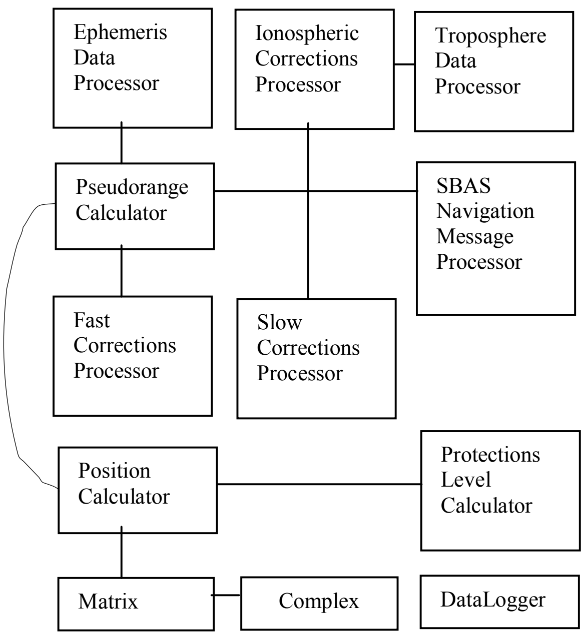

Figure 8: Data Processing Classes

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RINEX Parser

RINEX Parser is used to parse RINEX navigation and observation files. It includes two key classes: RINEXNavigationParser which is used to parse navigation files and RINEXObservationParser which is used to parse observation files. Both classes are accessed through RINEXParser class which provides an interface to rest of the components in the system. It can be used in real time or post processing mode. The class diagram of RINEX Parser is given in Figure 9.

BINEX Parser

BINEX Parser provides an interface to parse BINEX files [10] in real time or post processing modes. It is designed to support:

Record 0x01 = 1 for GNSS navigation information

Record 0x7f Subrecord 0x05 for GNSS Observables

The class diagram of BINEX Parser is given in Figure 10.

Correction Messages Parser

Correction Messages Parser module is used to parse wide area differential global navigation satellite system's correction messages broadcast by geostationary satellites in a binary format. A list of correction messages is given below.

Table 2: A list of correction messages

Message Type	Contents	Related Message	Relationship Parameter
0	Don't use for safety applications (Testing)		
01	PRN Mask Assignments	02-05, 07, 24, 25, 28	IODP
02~05	Fast Correction	06	IODF
06	Integrity Information	02-05, 24	IODF
07	Fast Correction Degradation Factor	01	IODP
09*	Geo Navigation Messages (X,Y,Z Time etc)		
10	Degradation Parameters		
12	SBAS Network Time, UTC Offset Parameters		
17	GEO SV Almanac		
18	Ionospheric Grid Point Mask	26	IODI
24	Mixed Fast Corr. / Long time SV Error Corr.		IODF
25	Long time satellite error corrections	01	IODP
26	Ionospheric Delay Corrections	18	IODI
27	SBAS Service Message	27	IODS
28	Clock Ephemeris Covariance Matrix Message	01	IODP
29~61	Reserved for Future Messages		
62	Internal Test Message		
63	Null Message		

User Interface

User interface module provides an access to user segment and allow user to visualize, monitor and analyze system's performance. It includes several screens that are used to display raw and preprocessed data and numerous static and dynamic graphs related to raw and preprocessed data. Key user interface elements are described below.

User Segment Software Screen given in Figure 11 allows user to launch software either in real time processing mode or post processing mode.

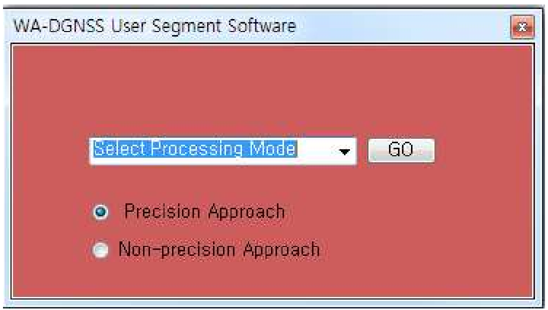

Figure 11: User Segment Software Screen

User Segment Software Real Time Processing Mode screen given in Figure 12 allows user to use various components of User Segment software in real time processing mode.

Receiver Activity Screen given in Figure 13 is used in a real time processing mode to display several important items to help user to understand how the receiver is being used and its current operating conditions.

6. SOFTWARE CHARACTERISTICS

User Segment software of Korean wide area differential global navigation satellite system is made of several independent and reusable modules that can be modified and tested separately. The modules can be easily added or replaced into user segment software. The current version processes global positioning system and wide area differential global navigation satellite system data but can be easily extended to support various global navigation satellite systems such as GLONASS and Galileo.

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7. CONCLUSION

The user segment software performs numerous functions such as calculation of ionosphere and troposphere delays, processing of correction messages, and data quality monitoring. It is made of several independent and reusable modules that can be modified and tested separately.

In this study a detailed design of user segment software of Korean wide area differential global navigation satellite system is described in terms of UML architectural and class diagrams. The study also describes key algorithms for processing correction messages and key user interface elements.

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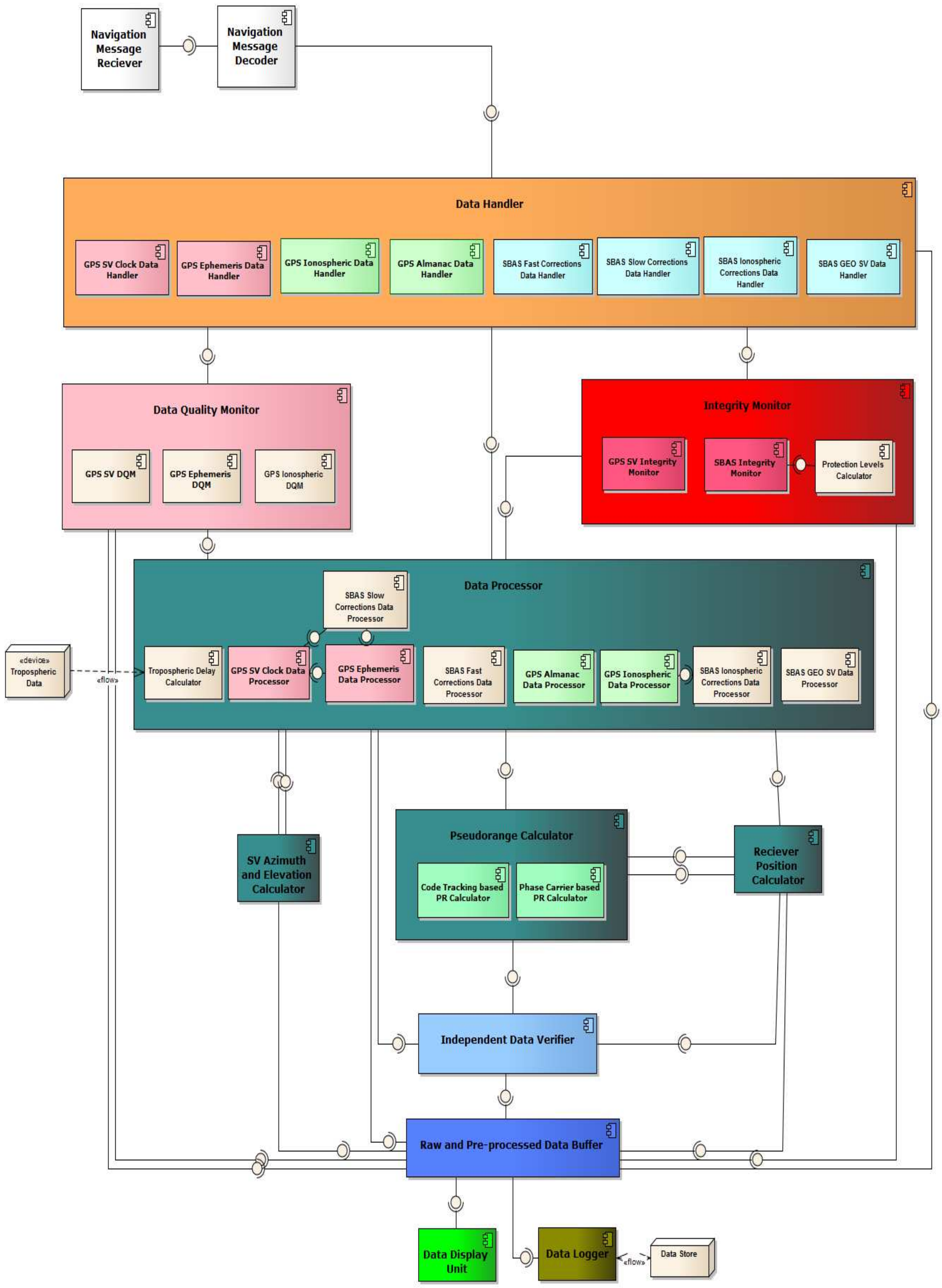

Figure 3: User Segment Software Architecture

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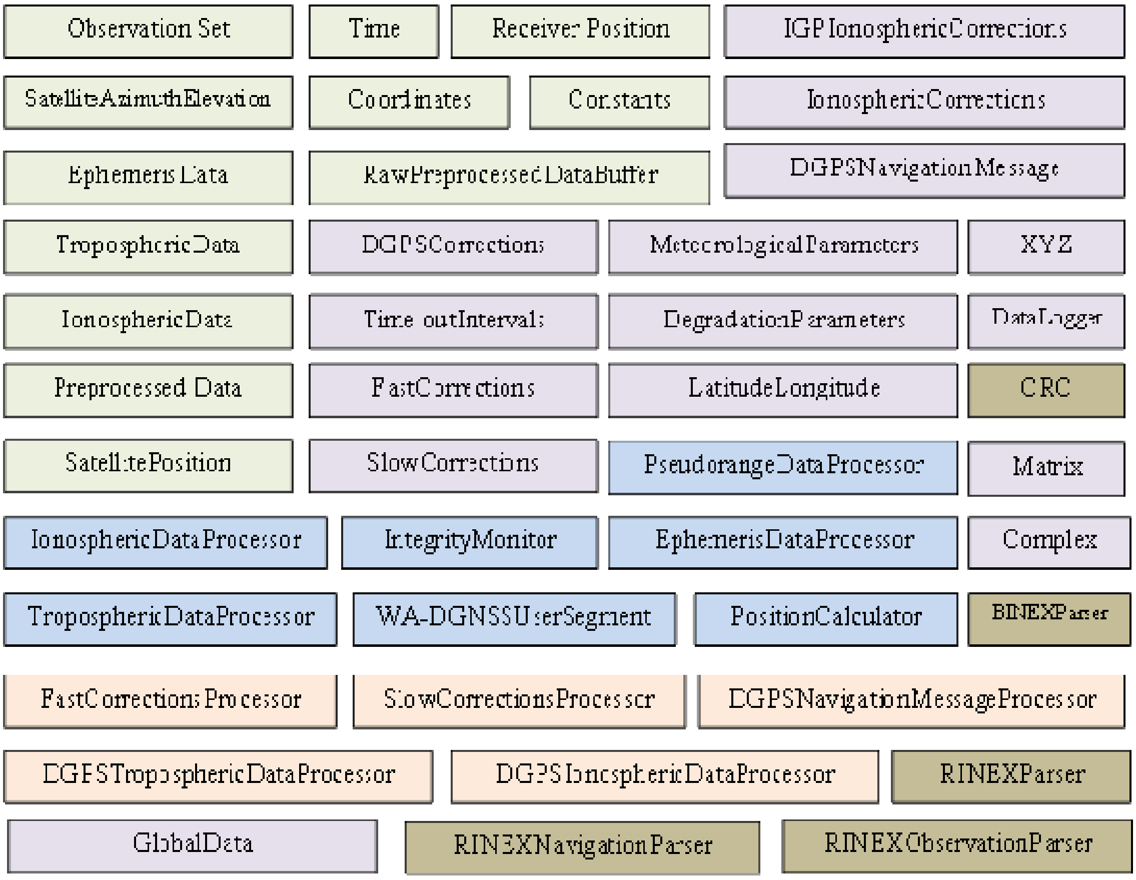

Figure 7: Key Classes of User Segment Software

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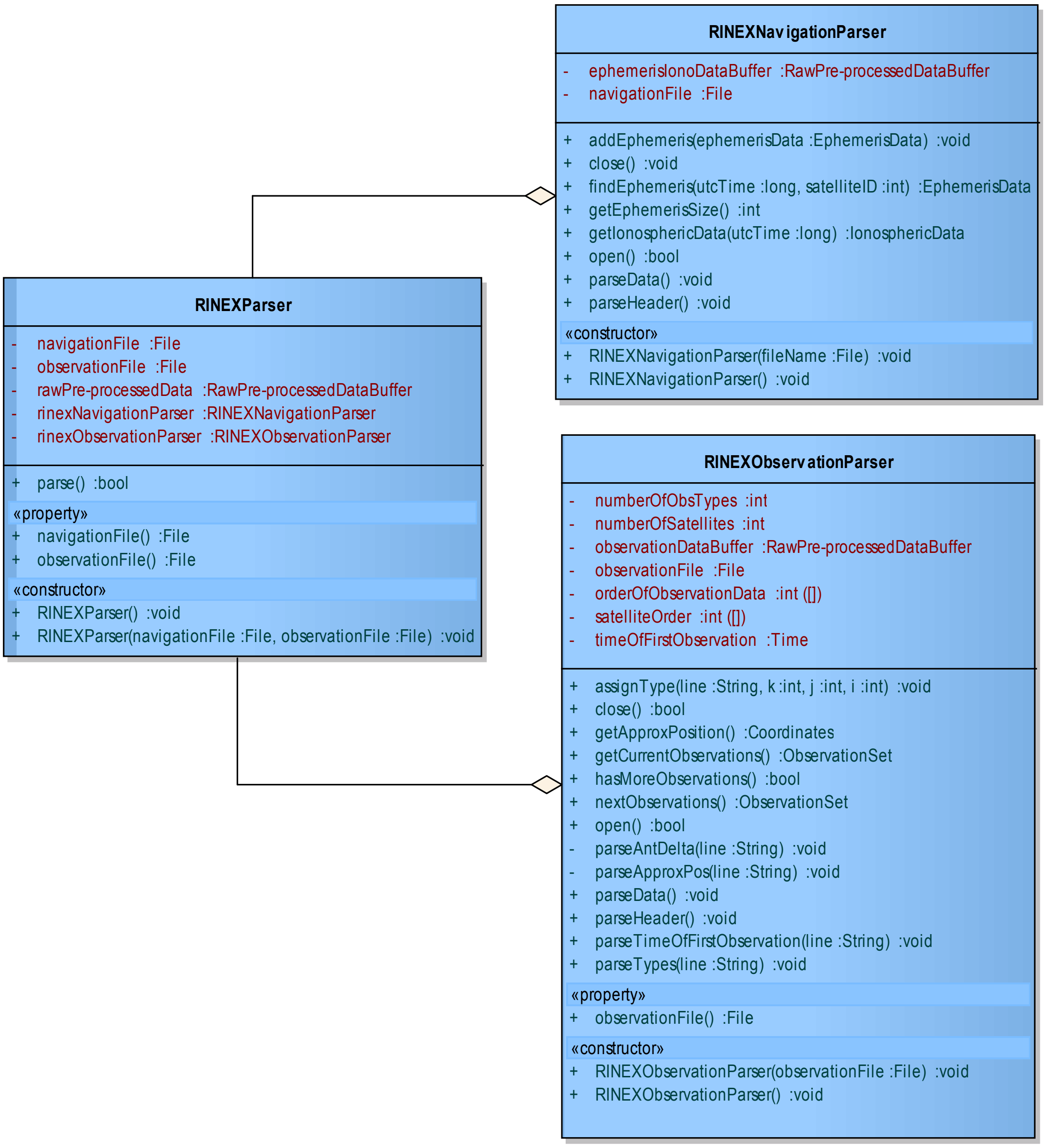

Figure 9: Class Diagram of RINEX Parser

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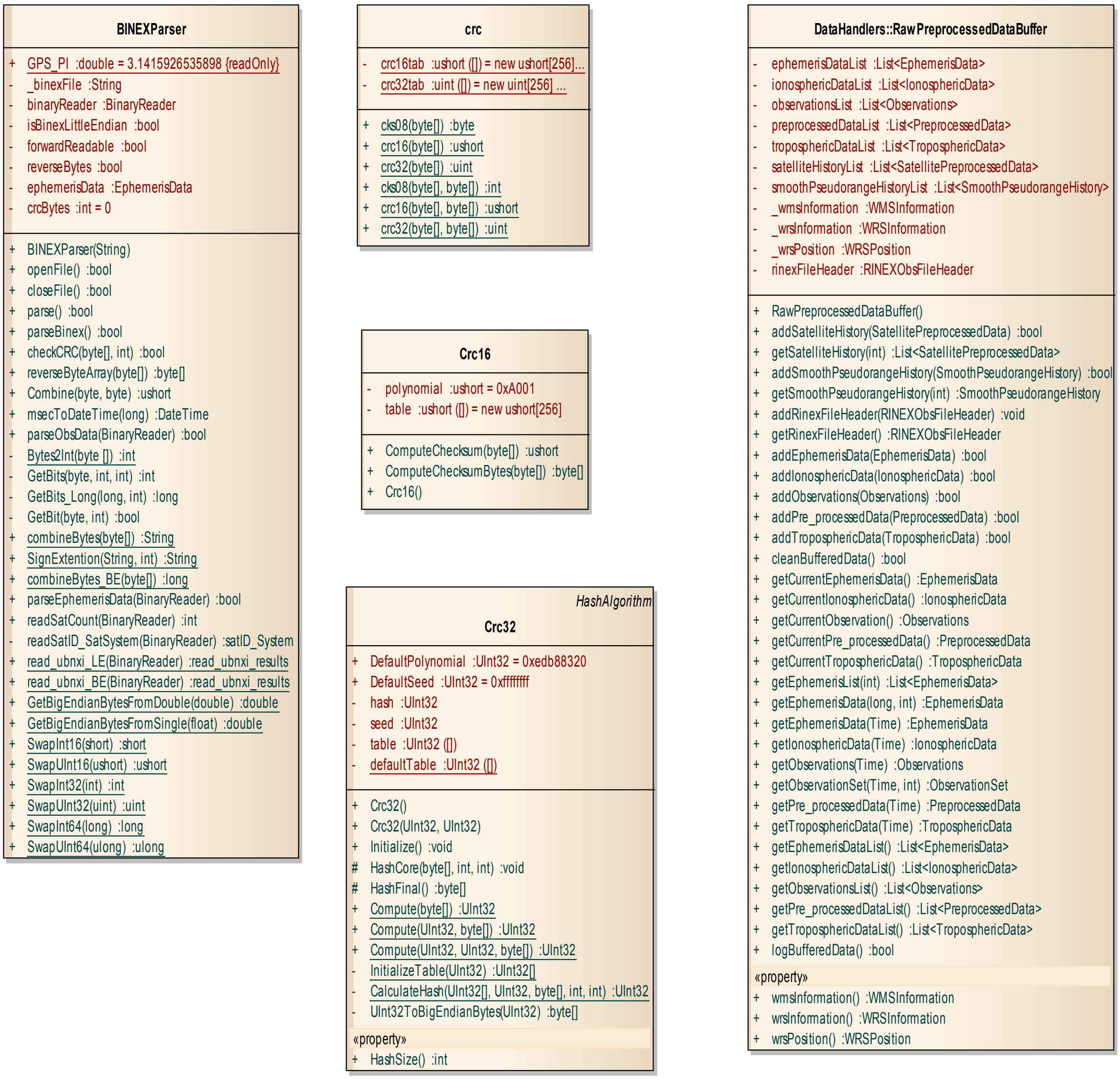

Figure 10: Class Diagram of BINEX Parser

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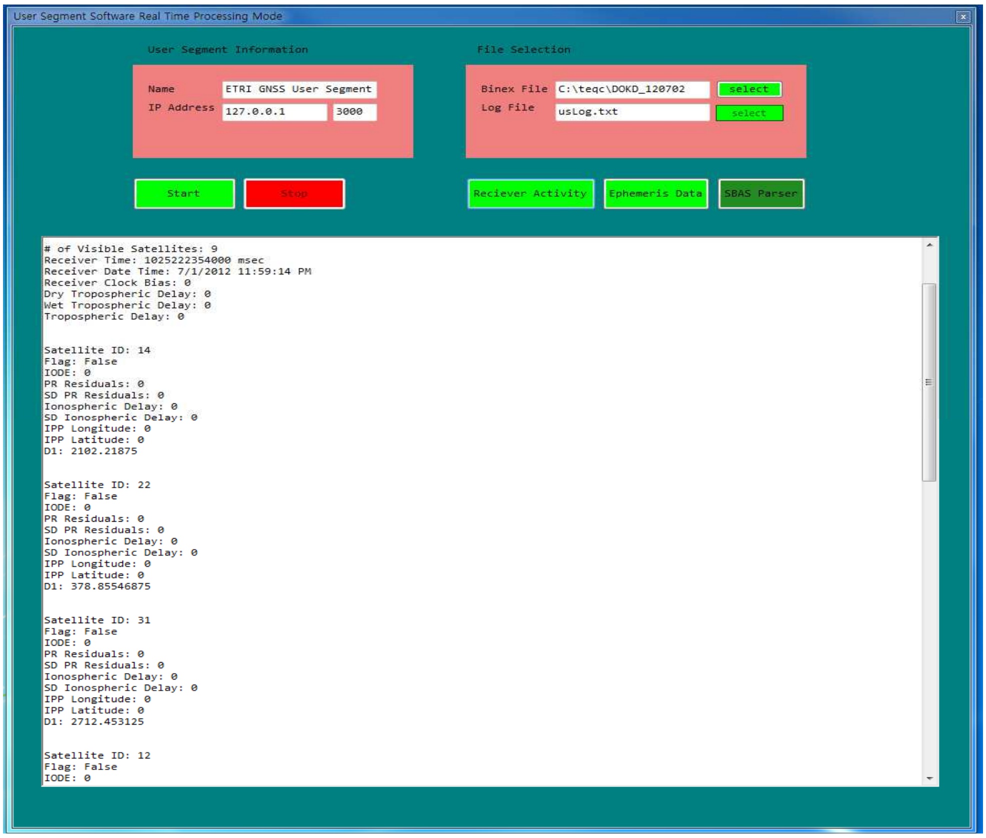

Figure 12: User Segment Software Real Time Processing Mode Screen

Figure 13: Receiver Activity Screen