The Reliability and Safety Enhancement Method of GNSS for Train Control Application

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Abstract: Global Navigation Satellite System(GNSS) is world-wide positioning infrastructure using navigation satellites. GNSS is applied to various positioning applications. To apply GNSS to safety-related public transportation system, a higher reliability and safety must be ensured. In Korea, the research on ground based augmentation system for GNSS and its applicability for transportation system has been progressed. In this paper, we present the integrity level of Korean augmentation system and analyze the integrity level of GNSS in the railway domain. Then we propose dual-mode GNSS configuration method which is applicable to train control which safety and reliability of higher level are required. We also analyze the reliability and safety of the configuration method by calculating various positioning failure rates.

1. Introduction

GNSS, satellite navigation infrastructure using satellites, is used for various applications such as survey, navigation and others. Several GNSS have been operated currently such as GPS of U.S., GLONASS of Russia. However, both GPS and GLONASS were developed initially for military use so its commercial application or service can be limited. In Europe, civilian GNSS – GALILEO is in the process of development and it is scheduled to be operational in 2012. Currently GNSS application to railway is limited in general application fields, such as freight tracking, track and geometric survey. Although it is essential for GNSS to ensure GNSS system integrity to be applied to safety-related railway application fields (e.g. train control), currently GPS does not provide any integrity information to user directly. In order to apply GNSS to safety related railway application fields, GNSS system's integrity information should be provided. In this paper, we present the current status of DGNSS service, the development concept and integrity level of Korean ground-based augmentation system which will be constructed in Korea, and translate the integrity level of GNSS to railway aspect's reliability and safety. Finally, we propose dual-mode GNSS configuration method which is applicable to the safety related railway application fields such as train control and evaluate the reliability and safety of the configuration method by calculating dangerous failure rate and service failure rate of the configuration method.

2. Ground-base Augmentation System for GPS integrity Assurance in KOREA

There are various systems being applied to ensure the integrity of GPS satellite signal. Those systems are mainly classified into two groups; one is SBAS(Satellite Based Augmentation System) using augmentation satellites, the other is GBAS(Ground-Based Augmentation System) using a reference stations on the ground. The representative SBAS being operated are WASS in the U.S., EGNOS in Europe Union and MSAS in Japan and the representative GBAS is LASS in the U.S. In addition, European GNSS, GALILEO, is developing which is expected to provide integrity information from navigation satellite to user receiver by through SoL(Safety of Life) service. In Korea, MLTM (Ministry of Land, Transport and Maritime Affairs) has provided NDGPS (National wide DGPS) service since 1999 for the sake of safety of coastal sea traffic. Nowadays Korea's NDGPS is operating through the 11 coast reference stations and 6 in-land reference stations. 6 in-land reference stations are additionally planned to establish within 2008[1].

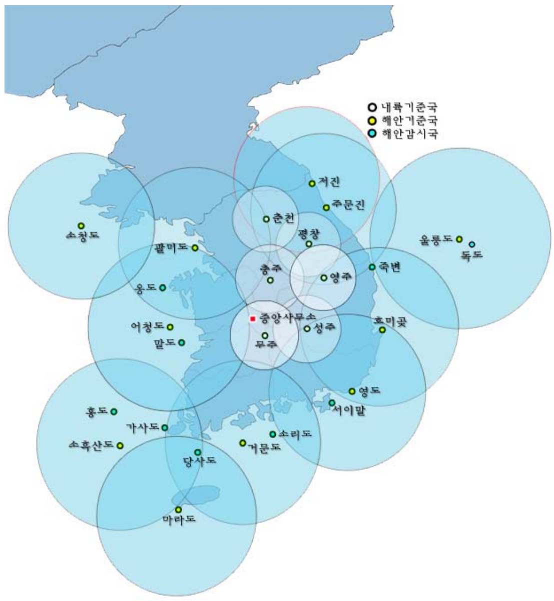

Figure 1. NDGPS Service Coverage in Korea

Presently, providing service is range correction service for GPS, through RTCM-SC104 and typical accuracy is sub-meter grade. However, NDGPS provides only DGPS data currently. In order to apply GNSS to the public transportation system and other safety-related system in Korea, it is important to ensure integrity on GPS SIS. Recently the research on ground-based augmentation system for ensuring integrity of GPS and GALILEO and its applicability to the public transportation system have been performed in Korea. Main object of this research is the development of GRID based integrity monitoring and correction technology for GPS and GALILEO. Especially the target integrity level for GPS L1 signal in this research is the same as the level for GALILEO SoL which is given in table 1. The concept of new GNSS Augmentaion System is presented in figure 2. If the integrity monitoring and information service for GPS L1 signal are possible through this research and GALILEO is operating, two GNSS having the same level of integrity are available in KOREA.

Table 1. Integrity requirement of GALILEO SoL Service

Category		Safety of Life (Critical Level)
Integrity	Alarm Limit	HAL: 12m, VAL: 20m
	Time-To-Alarm	6 seconds
	Integrity Risk	$2x10^{-7}$/150 sec
Continuity Risk		$8x10^{-6}$/15 sec
Availability of Integrity		99~99.9%

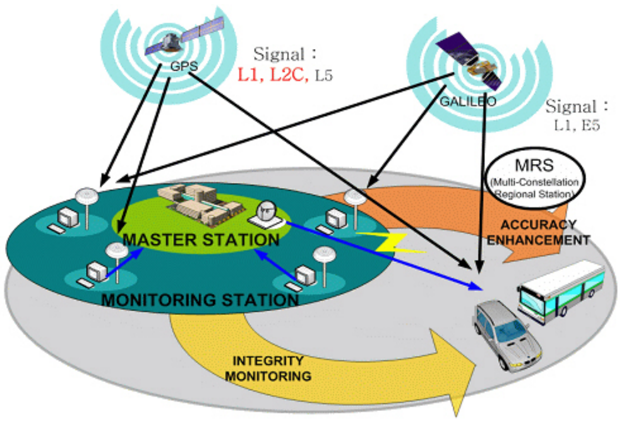

Figure 2. GNSS Augmentation System Concept

3. Translation on Reliability and Safety Requirements of GNSS

GNSS performance requirements are derived from the aviation system, because GNSS is applied to aviation systems early. However, reliability and safety concept of GNSS and the concept of railway are not same. So the concept has to be translated in railway domain. So, In order to apply GNSS to railway system properly, it is necessary to translate the reliability and safety requirement of GNSS which is defined in the aviation domain to the requirements in railway domain. To apply GNSS to railway application fields suitably, GNSS positioning failure classification should be needed. GNSS positioning failure classification is presented in figure 3. On the assumption that the visibility for navigation satellite is fully ensured and visibility does not make a failure, GNSS positioning failures can be classified into GNSS SIS failure and GNSS user failure. GNSS SIS failures can be sub-categorized into satellite payload failure, unpredicted propagation medium behavior and ground control system failure. GNSS user failure also can be sub-categorized into receiver failure.

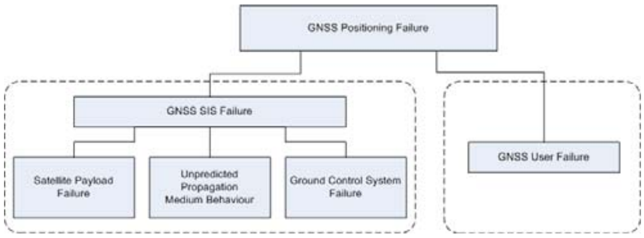

Figure 3. GNSS Positioning Failure classification

GNSS SIS failure can be grouped in a way based on safety concept; that is, dangerous failure and service failure. Dangerous failure refers to the failure event triggering the accident, such as train collision and derailment, that integrity alert does not occur when any failures are found on GNSS SIS. The probability of dangerous failure can be calculated by using the requirements of integrity risk, continuity risk and time to alert. Service failure refers to the failure event causing any positioning service interruption due to the integrity alert and it can be derived by converting continuity risk [2].

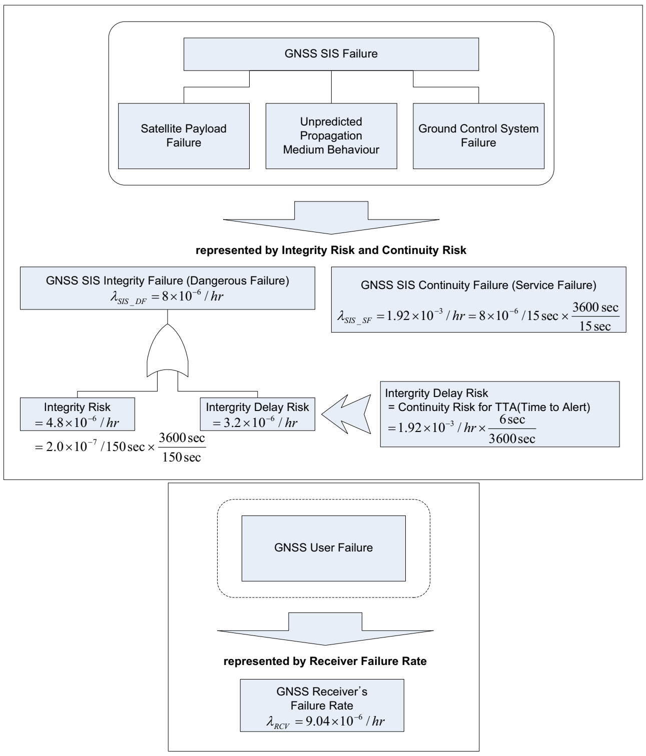

Figure 4. GNSS Positioning Failure classification

Figure 4 represents various GNSS failures and its failure rates. Since GNSS positioning failures are distinguished into dangerous failure and service failure, the failure rate for each failure category also can be defined as dangerous positioning failure rate and service positioning failure rate. GNSS dangerous positioning failure rate can be defined as the sum of GNSS SIS dangerous failure rate and GNSS user dangerous failure rate as shown in Figure 5. Likewise, GNSS service positioning failure rate is defined as the sum of GNSS SIS service failure rate and GNSS user service failure rate as shown in Figure 5.

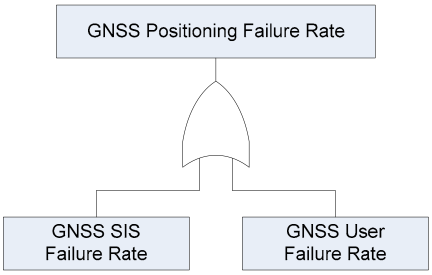

Figure 5. GNSS Positioning Failure Rate

In order to calculate GNSS dangerous positioning failure rate and service positioning failure rate, we can use integrity risk, continuity risk suggested in GALILEO SoL SIS requirements and GNSS receiver failure rate(λ_{RCV}). In here GNSS receiver failure rate is $9.04\text{x}10^{-6}$/hr which is derived from MTBF(Mean Time Between Failures) of commercial GPS receiver, on the assumption that GNSS user dangerous failure rate and user service failure rate are the same. As a result, we got $1.704\text{x}10^{-5}$/hr as GNSS dangerous positioning failure rate and $1.929\text{x}10^{-3}$/hr as service positioning failure rate.

4. The Enhancement of Reliability and Safety on GNSS for Train Control Application

As described in section 3, stand-alone GNSS system is inappropriate to be applied to safety related railway system because its dangerous positioning failure rate and service positioning failure rate do not satisfy the target reliability and safety in safety related railway application. To apply GNSS to safety related railway application, reliability and safety of GNSS must be improved.

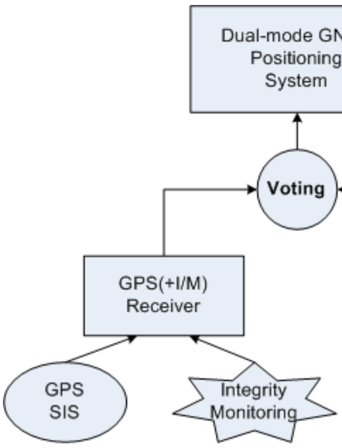

Figure 6. Dual-mode GNSS Configuration

And it can be achieved to the reliability and safety improvement of GNSS for safety related railway application through the integration of two GNSS systems (GNS with integrity monitoring and GALILEO SoL) in voting structure as shown in Figure 6. Namely, Dual mode GNSS configuration is established by coupling of the GPS with integrity monitoring and GALILEO SOL independently. So we can expect to improve the dangerous positioning failure rate using independently two GNSS that have the same integrity level.

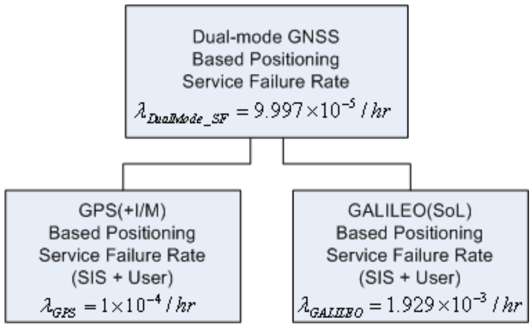

Figure 7. Service Failure Rate of Dual-mode GNSS Configuration

Figure 7 represents the service failure rate of dual-mode GNSS configuration. It should be noted that GPS with integrity monitoring and GALILEO SoL has different failure rate since they are different GNSS system and their continuity risks are also different from each other. Consequently, service failure rate of dual-mode GNSS based positioning system is derived as $9.997\text{x}10^{-5}$/hr by using effective failure rate equation approximation as given in equation (1)[4]. The GPS continuity risk data used in here is calculated based on the operation data collected from 1994 until 2000[3].

According to dual-mode GNSS configuration, dangerous failure rate can be represented by multiplying each dangerous failure rate of GPS with integrity monitoring and GALILEO SoL on the assumption that both dangerous failure rate of GPS SIS and GALILEO SoL SIS have the same integrity level. And it is assumed that the failure rate of GALILEO receiver is same as commercial GPS receiver.

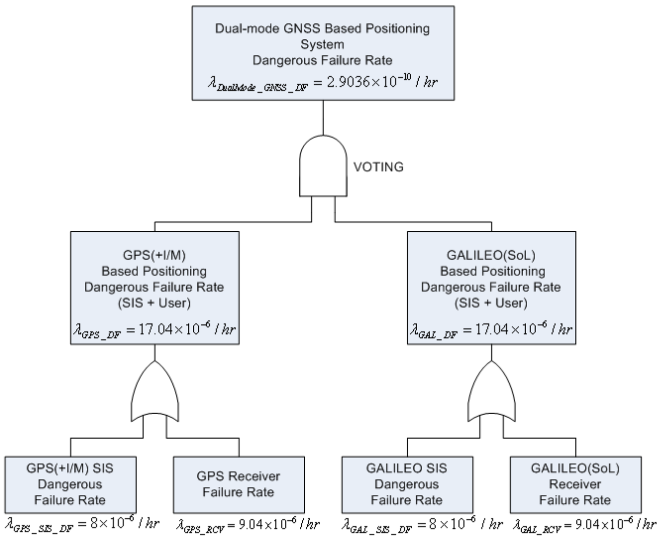

Figure 8. Dangerous Failure Rate of Dual-mode GNSS Configuration

Therefore, the dangerous failure rate of dual-mode GNSS based positioning system $\lambda_{DualMode\_GNSS\_DF}$ is derived as $2.9036\text{x}10^{-10}$/hr. In railway application, major dangerous failures causing catastrophic accident, such as death, injuries, are allocated to SIL(Safety Integrity Level) 4 and those failures should be managed that its failure rate remains under 10^{-8}/hr. Therefore, dual-mode GNSS configuration satisfies SIL 4 safety level since its dangerous failure rate is 2.9036×10^{-10}/hr.

5. Conclusion

In Korea, a research on ground based augmentation system for integrity assurance of GPS satellite signal and its applicability to railway application have been in progress. The target integrity level for GPS L1 signal established in the research is the same as the level for GALILEO SoL. In this paper, we presented the integrity level of Korean augmentation system and analyzed the integrity level of GNSS in the railway aspect's reliability and safety. Then we proposed dual-mode GNSS configuration method which is applicable to train control which safety and reliability of higher level are required. We also analyzed the reliability and safety of the configuration method by calculating service and dangerous positioning failure rates.

Service positioning failure rate of dual-mode GNSS positioning system was calculated as 9.997×10^{-5}/hr, and it is improved than only one GNSS is being used. The dangerous positioning failure rate of dual-mode GNSS based positioning system $\lambda_{DualMode\_GNSS\_DF}$ was derived as 2.9036×10^{-10}/hr, which means it satisfies SIL 4 safety level in the railway domain.

The visibility has main effect on availability of GNSS based railway application. By coupling two GNSS commonly, the improvements of availability and accuracy are expected. However, for the improvements of integrity level, two GNSS must be used by independently coupling. Also, for the improvements of availability, it is needed to integrate with various auxiliary sensors such as odometer, doppler sensor, IMU(Inertial Measurement Unit), transponder, and so on.

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