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INHA UNIVERSITY

AUTONOMOUS NAVIGATION LAB

# Inha University

## Autonomous Navigation Laboratory

# GNSS

# Autonomous Driving Car

# Autonomous Navigation Lab

Est. Jan. 4th , 2016.

## Leader

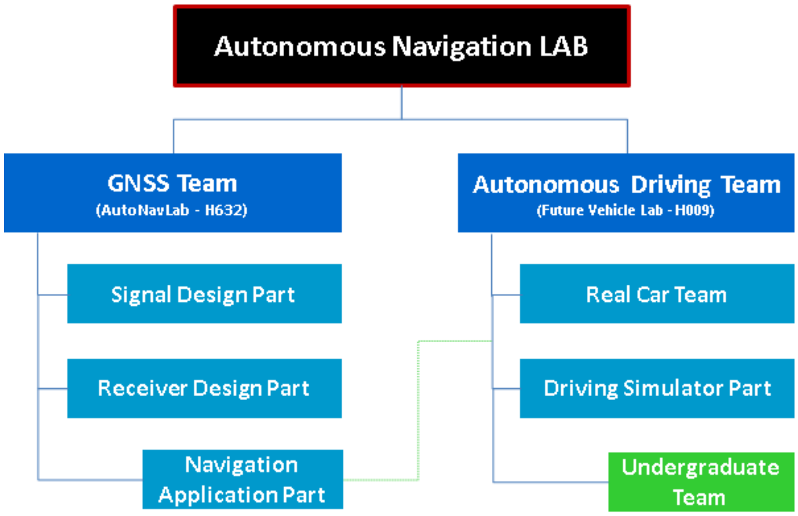
- Jong-Hoon Won (Ph. D.)
- Inha University, Department of Electrical Engineering, Professor
  - Tenured('15 – present)
- Inha University College, Department of Future Vehicle Engineering, Adjunct Professor
  - Tenured ('17 – present)
- Agency for Defense Development, Research and Development Advisory Committee Member
  - Tenured ('16. ~ '18)
- Bundeswehr University, Department of Aerospace Engineering, Space Technology Engineering Laboratory, Research Director
  - Tenured ('11 – '15)

# About Us

Inha University Autonomous Navigation Laboratory was established in 2016 within the Department of Electrical Engineering at Inha University and conducts various research in the fields of GNSS satellite navigation and autonomous vehicles.

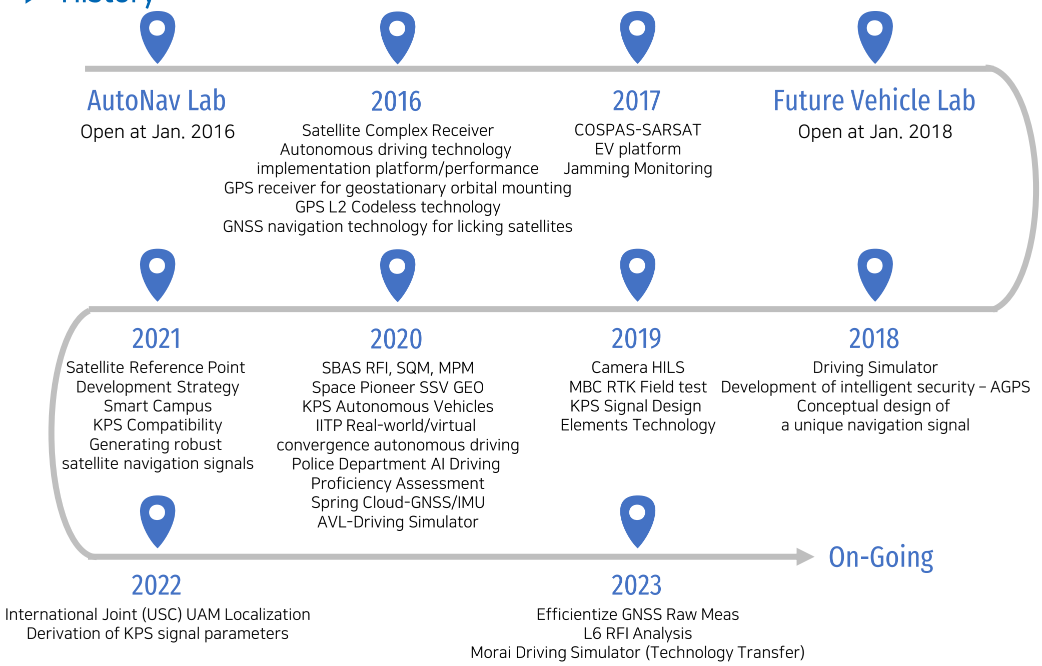
### ▶ Team Members (Oct. 2024)

- Ph. D. students : 3
- Master students : 10
- Under-graduate : 2




### ▶ ANL's Key Words


### ▶ History

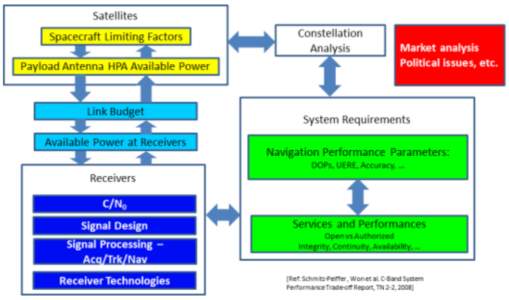


# Signal Design Techniques for KPS Development [TRL 3]

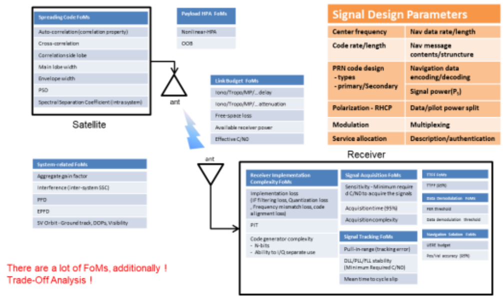
## ▶ GNSS Signal Design

The development of GNSS systems involves designing and analyzing satellite orbits based on service performance requirements (navigation performance, service performance), and it includes satellite payload analysis (spacecraft limiting, payload antenna HPA available power), satellite-receiver channel analysis, and receiver subsystem design and analysis (C/N0, signal design, signal processing, receiver technologies).

The design of GNSS signals involves determining the optimal signal design parameters that satisfy service performance requirements while considering trade-offs between various signal design parameters, satellite payload, channel, and receiver subsystem performance indices. To systematically perform this series of processes, a step-by-step signal design simulator tool is essential.



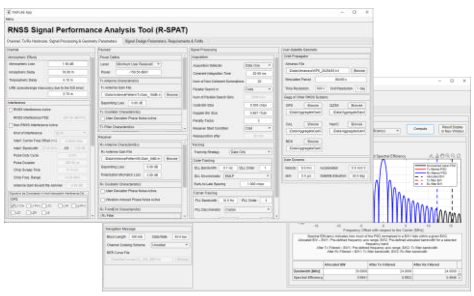

Signal Design Methodology



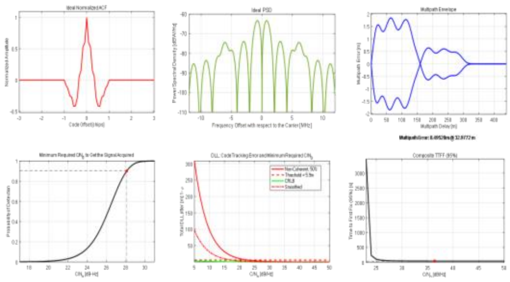

Signal Design Parameters and Performance Indices

## ▶ Signal Design Tool 1

The analytical simulator is a MATLAB-based tool that parameterizes each element of the GNSS transceiver chain and provides analysis of signal performance based on relationships between parameters and navigation signal performance indices. Users can utilize a GUI to configure modulation schemes, spreading codes, navigation messages, and waveform models for the desired signal design. Additionally, users can configure channel characteristics, interference, and multipath environments. Furthermore, the tool allows for modeling of various receiver specifications.



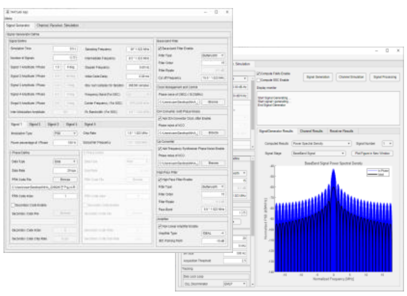
Analytical Simulator GUI



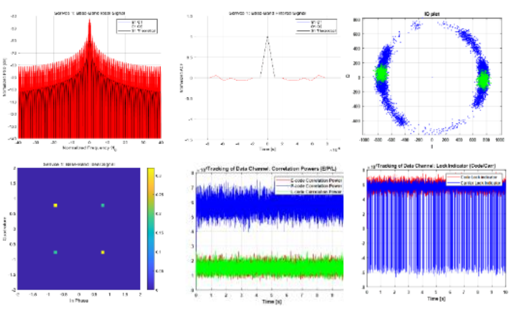
Analytical Simulator Output Performance Index Examples

## ▶ Signal Design Tool 2

The numerical simulator is a MATLAB-based simulation tool that performs the entire signal transmission and reception chain process, from signal generation on actual satellite payloads to signal processing at ground receivers. The signal generation and channel modules of this tool are implemented in software to generate signals similar to actual GNSS signals, while the receiver module is configured with RF front-end, signal acquisition, and tracking components similar to real GNSS receiver models.



Numerical Simulator GUI



Numerical Simulator Output Performance Index Examples

# Features

## Signal performance FoM

- Criteria for design parameters and adjustments
- An analytical tool to evaluate overall service performance from a signal perspective and optimize it according to the requirements of providers and users.

## Key FoMs

- Signal Information Performance (PSD, ACF)
- Link Budget Performance (User Received Power, Effective C/N0, EIRP)
- Signal Propagation Performance (Ionospheric Error, Tropospheric Error, Multipath Error)
- Jamming Performance (Jamming Resistance Factor, J/S Margin)
- Compatibility Performance (SSC, PFD, EPFD, etc.)
- Spreading Code Performance (Autocorrelation/Cross-correlation Histogram, Correlation Percentile)
- Signal Acquisition Performance (Minimum Required C/N0, Acquisition Time)
- Signal Tracking Performance (DLL/PLL/FLL Stability, Average Cycle Slip Time)
- Data Decoding Performance (BER, FER)
- TTFF
- System Performance (Main Lobe Gain, UERE Budget, Position Accuracy, etc.)

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# Features

## Fully Reconfigurable Capability

- Easily add new signals
- Free to choose processing target signal combinations
- Convenient modification of signal component parameters and processing parameters

## Supported GNSS

- GPS
- GLONASS
- Galileo
- BDS
- QZSS
- NavIC
- KPS

## Signal Acquisition and Tracking Acceleration

- GPU-Based Signal Acquisition
- Integer for Signal Tracking Correlator Using MEX Functions

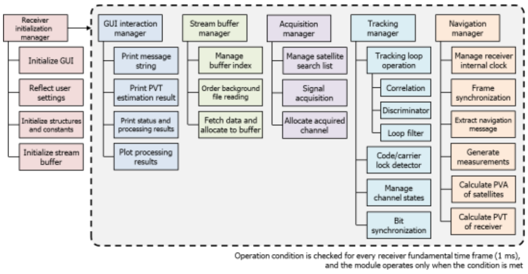
## Additional Features

- API support
- RINEX file out
- Pulse blanking-Based RFI Mitigation
- Direct State Signal Tracking Kalman Filter

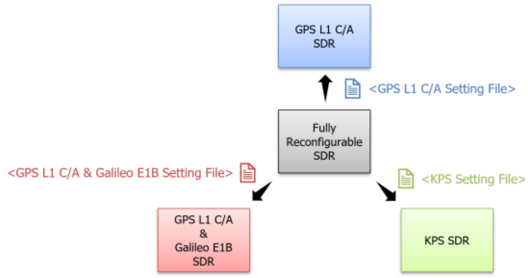
# GNSS/KPS SDR Receiver [TRL 4]

## ▶ Fully Reconfigurable Capability

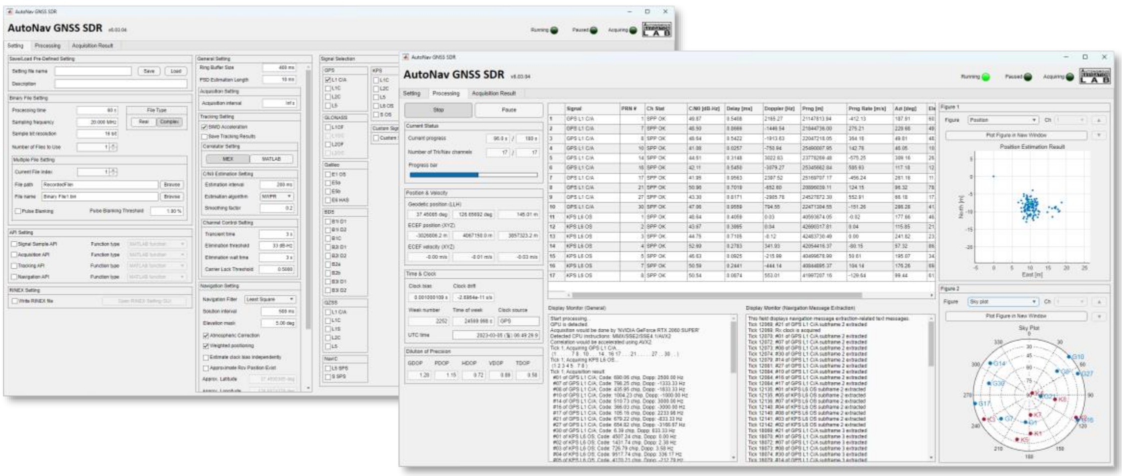
SDR receivers inherently possess reconfigurable capabilities. Through appropriate design of signal processing structures and data structures, the maximization of this reconfigurable capability is achievable. SDR receiver that support fully reconfigurable capabilities enables changes in user settings to modify target signal combinations and parameters for each signal, without structural alterations. Moreover, they facilitate the easy addition of new signals that were previously absent. Therefore, they are suitable for new GNSS(e,g, KPS) research. The characteristics of SDR receivers are determined by modifications and replacements of configuration files, resulting in each SDR receiver operating entirely differently.




GNSS/KPS SDR Receiver Signal Processing Architecture




Fully Reconfigurable Capability




GNSS/KPS SDR Receiver GUI (Example of Multi-GNSS processing with GPS L1 C/A and KPS L6 OS)

## ▶ List of Available Signals for Generation and Processing

Most GNSS public service signals and all types of KPS signals processing are supported.

| System | Signal | Acquisition/ Tracking | Message Extraction | Navigation |
|---|---|---|---|---|
| GPS | L1 C/A<br>L1C (D+P)<br>L2C<br>L5 (I+Q) | O<br>O<br>O<br>O | O<br>O<br>O<br>O | O<br>O<br>O<br>O |
| GLONASS | L1OF<br>L2OF | O<br>O | O<br>O | O<br>N/V* |
| Galileo | E1 OS (B+C)<br>E5a (I+Q)<br>E5b (I+Q)<br>E6 HAS (B+C) | O<br>O<br>O<br>O | O<br>O<br>O<br>X | O<br>O<br>O<br>- |
| BDS | B1I<br>B1C (D+P)<br>B2I<br>B2a (D+P)<br>B2b<br>B3I | O<br>O<br>O<br>O<br>O<br>O | O<br>O<br>O<br>O<br>X<br>O | O<br>O<br>O<br>O<br>X<br>O |
| QZSS | L1 C/A<br>L1C (D+P)<br>L1S<br>L2C<br>L5 (I+Q) | O<br>O<br>O<br>O<br>O | O<br>O<br>X<br>O<br>O | O<br>O<br>-<br>O<br>O |
| NavIC | L5 SPS<br>S SPS | O<br>N/V | O<br>N/V | O<br>N/V |
| KPS | Any | | | |

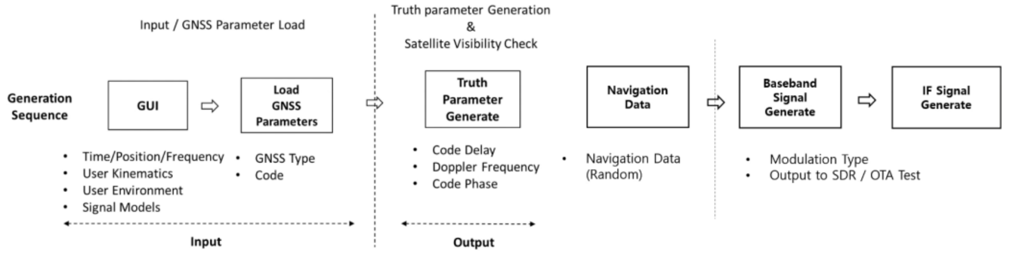
*N/V: Implemented, but not verified enough

# GNSS/KPS Signal Generator [TRL 3]

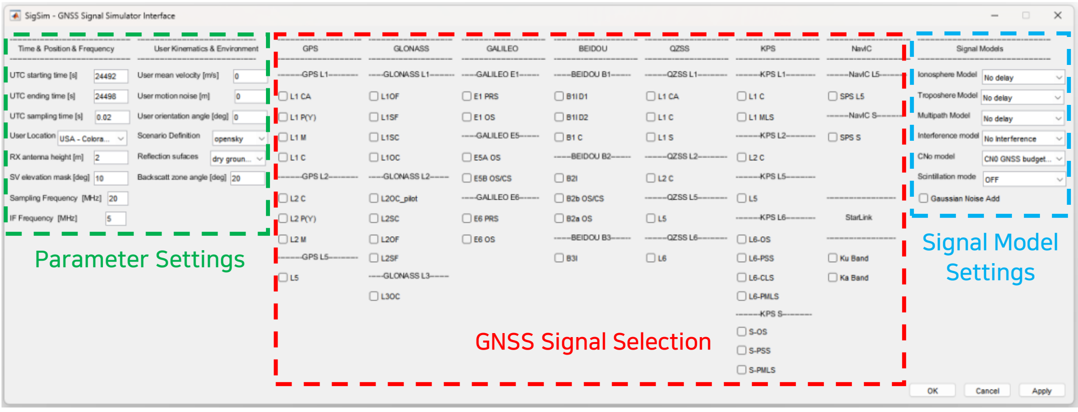
## ▶ Signal Generator

The software-based signal generator is designed to generate various GNSS signals by adjusting existing GNSS signals to different user conditions and signal characteristics. This flexibility and scalability allow for signal generation by adjusting several parameter values for both existing signals and future KPS signal candidates.

Users input parameters such as their location, time/kinematic situation, multipath effects, and antenna-related parameters we able to set via a GUI. These parameters are then used along with pre-set system constants and almanac information to generate time-varying parameters (such as code delay, carrier phase, Doppler, C/N0) corresponding to the input conditions. Subsequently, navigation data bits are created for the selected signals, and the generated time-varying parameters are used to produce baseband and IF signals using appropriate modulation techniques.



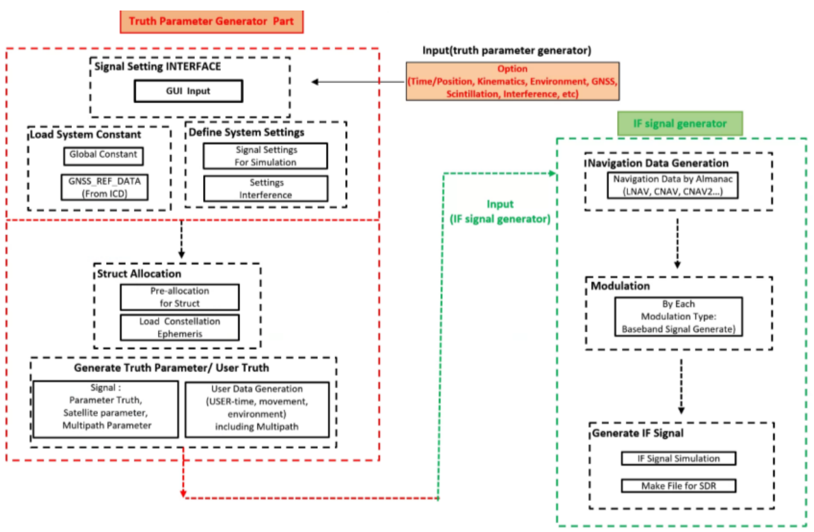

Block diagram of GNSS/KPS Signal generator




GNSS/KPS Signal Generator GUI

## ▶ Fully Reconfigurable Capability

The GNSS signal generator is designed to support software-based Multi-constellation/Frequency, allowing for scalability to support future KPS signal candidates. It incorporates reconfigurability features, enabling the generation of signals by simply changing parameters and user environment settings. Additionally, it is implemented to support the creation of custom signals, providing flexibility for user-defined signal generation.




GNSS/KPS Signal Generator Architecture

# Features

## Supported GNSS Signals

- GPS
- GLONASS
- Galileo
- QZSS
- KPS

## Reconfigurable Parameters

- Frequency Band, Sampling Frequency, Intermediate Frequency
- Chipping Rate, PRN, Demodulation Method, Secondary Code, and other PRN code-related settings
- Types of Navigation Data and Data Rate
- User Position and Environment, Antenna-related Settings, Signal Delay Model, etc.

# FPGA-based Real-Time GNSS Signal Generator (On-going) [TRL2]

## Features

### Signal Generator Module

- Control PC
- Processing System (PS)
- Programmable Logic (PL)
- RF front-end

### Hardware

- ADRV9361-Z7035: Main Operations Performed
- ADRV1CRR-FMC: I/O and Interface Expansion

### Hardware Specifications

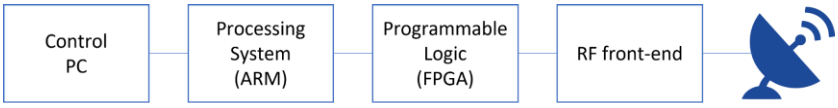
- RF band: 70 MHz ~ 6 GHz
- Channel BW: <200 kHz ~ 56 MHz
- Processor: Dual ARM® Cortex™-A9 MPCore™ running at 800 MHz
- Programmable logic: 275K Kintex-7 logic cells with 900 DSP48 slices

### Target GNSS Signal

- GPS L1/L5 12 Channel
- Galileo E1/E5a 12 - Channel
- QZSS L1/L5 8 - Channel
- KPS L1/L5 8 - Channel

## ▶ FPGA based Real time GNSS Signal Generator

GNSS signals typically have bandwidths ranging from several MHz to tens of MHz. To generate these signals without distortion in the digital domain, sampling frequencies of several tens of MHz are generally required. Generating such signals on a General Purpose Processor (GPP) like a CPU can be computationally burdensome, making real-time signal generation impractical. On the other hand, FPGAs utilize resources in the logic domain to enable high levels of parallel computation, allowing for real-time generation of GNSS signals. At Inha University's Autonomous Navigation Research Lab, we are developing a real-time GNSS signal generator based on Zynq boards to leverage the advantages of both GPPs and FPGAs. A Zynq board integrates both a GPP and an FPGA, enabling us to perform computationally intensive operations such as satellite position calculation and reference signal computation on the ARM processor, which corresponds to the GPP. Simultaneously, we can handle it relatively simpler but computationally intensive tasks like GNSS Intermediate Frequency (IF) signal generation on the FPGA.

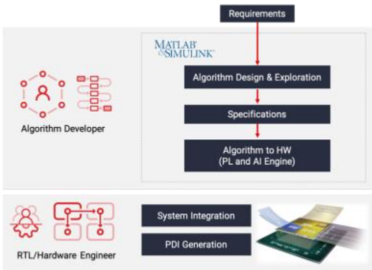



FPGA based Real time GNSS Signal Generator


Hardware of FPGA based Rel time GNSS Signal Generator

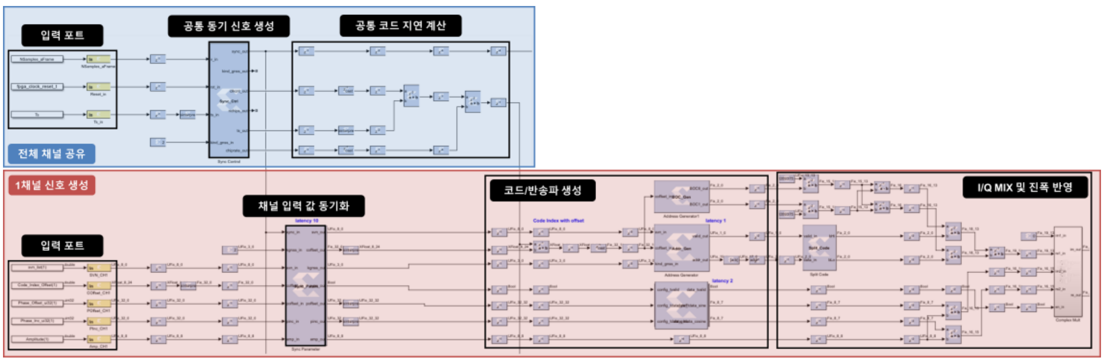
## ▶ Development of IF Signal Generation Logic

The IF signal generator logic to be executed on the FPGA is developed using Xilinx's Model Composer, implemented and verified in Simulink, and then converted into a bitstream executable on the board using Vivado and Vitis.




Xilinx Vitis Model Composer


GNSS Signal Generator Development Process

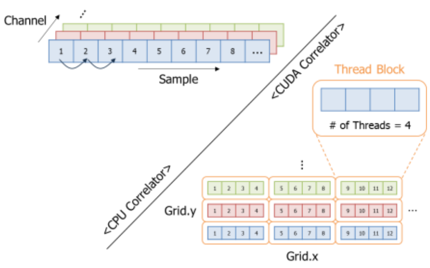



GNSS L1/L5 IF Signal generation logic

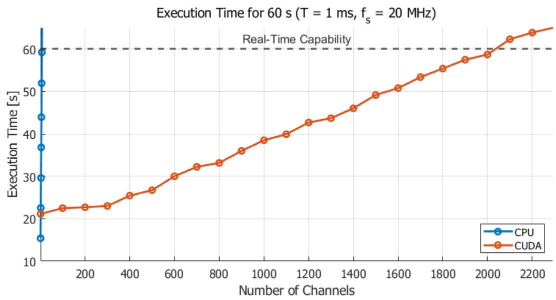
# GNSS Receiver/Simulator Advancement [TRL 3]

## ▶ CUDA-Based High-Speed GNSS Correlator

The GNSS correlator, which generates replica signals of the carrier and code and correlates them with the received signal, needs to operate at the same rate as the sample rate of the received signal, and requires independent correlation for each channel. When operated on a sequential processor like a CPU, it typically suffers from limited real-time processing performance due to the dual-loop structure over the signal samples and channels. On the other hand, a CUDA-based high-speed GNSS correlator leverages the thousands of cores in the GPU to parallelize the dual-loop structure, significantly reducing the time required for correlation in the receiver. This enables software receivers to achieve real-time processing performance. The CUDA-based high-speed GNSS correlator developed at Inha University's Autonomous Navigation Lab can operate in real-time for up to approximately 2050 channels at a sampling frequency of 20MHz.



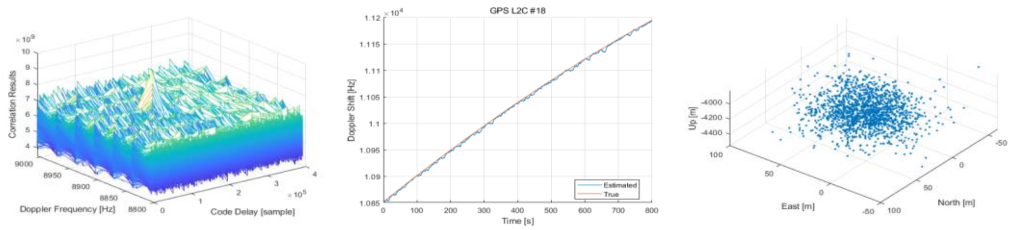

CPU-Based and CUDA-Based Correlator Processing Methods




Computation time (@20 MHz I/Q)

## ▶ Weak Signal Processing Algorithms for Geostationary Orbit (GEO) Satellites

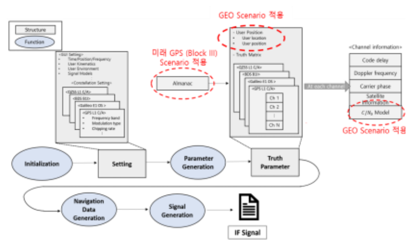
GNSS receivers mounted on geostationary orbit satellites operate in environments different from those on the ground. The primary characteristics of the reception environment for GEO satellites include weak signal power approximately 20dB-Hz and high Doppler frequencies of up to 10kHz. Therefore, specialized algorithms are required for GNSS receivers to operate on GEO satellites. The Autonomous Navigation Lab at Inha University has developed and optimized weak signal acquisition/tracking algorithms for GPS L1/L2 and Galileo E1 signals. Simulation results have demonstrated successful navigation solutions for 15 minutes using signals from over 6 visible GPS satellites with a power-to-noise density ratio (C/N0) exceeding 20dB-Hz in geostationary orbit, achieving a 3D standard deviation of 96.6 meters.




Results of Weak Signal Processing for Geostationary Orbit Satellites

## ▶ GNSS Simulator for Geostationary Orbit (GEO) Satellites

The GNSS simulator developed by the Autonomous Navigation Lab at Inha University can be extended to simulate scenarios for GEO using its flexibility. The GNSS simulator for GEO satellites utilizes satellite transmit antenna gain patterns measured and distributed by Lockheed Martin and calculates the received signal power through link budget calculations. Additionally, it generates almanac parameters considering the GPS block types.




# Features

## CUDA based Correlator

- Design of Logical CUDA Thread Allocation
- Acceleration using Shared Memory-based Reduction
- Optimization of Device-Host Communication
- Real-time operation for up to approximately 2050 channels (@20MHz I/Q)

## Weak Signal Processing Algorithm for Geostationary Orbit Satellites

- Acquisition Algorithm considering Code Doppler
- Optimized Weak Signal Acquisition/Tracking Parameters
- Aiding-Based Pseudorange Generation Algorithm
- Vector Tracking Algorithm

## GNSS Simulator for Geostationary Orbit Satellites

- Consideration of Earth Shadow and Ionospheric Regions
- Utilization of Actual GPS Satellite Transmit Antenna Patterns
- Distinction of Transmit Signal Power for Each GPS Block
- Calculation of Received Signal Power Using Link Budget

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# GNSS Jamming/Spoofing OTA Simulation and Monitoring Technology [TRL 3 ~ 4]

## Features

### In-Car Jamming Data Generator (ICJDG)

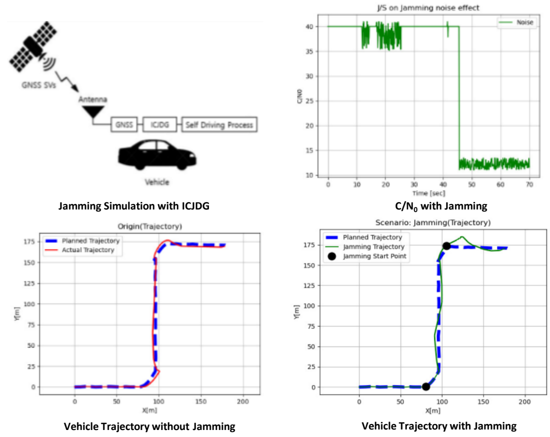
- Various radio interference scenarios can be reflected (jamming, spoofing, microjamming).
- Validation of autonomous driving algorithms considering radio interference.

### GNSS Jamming monitoring tools

- Customizable jamming scenarios
- Detection of jamming signals using 2-D images (spectrograms)
- Variable parameters such as window type and length for STFT analysis according to the scenario
- Analysis of jamming environments using post-processing methods with recorded signals

### ▶ Jamming Generation Simulation Technology

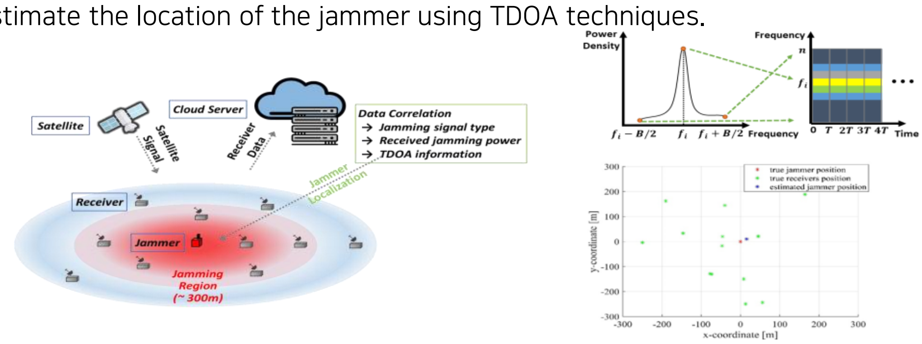
GNSS technology enables the acquisition of users' position, velocity, direction, and time information globally, serving as a key component in technologies such as autonomous vehicles, drones, and unmanned aerial vehicles. However, signals transmitted from satellites located in high-altitude orbits above 20,000 km exhibit weak signal strength at ground level. This characteristic makes GNSS sensors vulnerable to jamming and spoofing attacks. Jamming saturates the receiver's front-end, blocking GNSS signals, while spoofing manipulates positioning results by mimicking real GNSS signals. Therefore, research is underway from various perspectives to develop technologies to counter jamming and spoofing. However, jamming and spoofing signals not only affect experimental GNSS receivers but also nearby receivers, posing constraints on constructing Hardware-in-the-Loop Simulation (HILS) environments including jammers and spoofers. To overcome this challenge, the Autonomous Navigation Lab at Inha University has developed an In-Car Jamming Data Generator (ICJDG) that reflects the impact of jamming and spoofing signals on GNSS positioning results. The ICJDG generates position errors based on user-defined jamming and spoofing scenarios, allowing evaluation of the effects of jamming and spoofing on the development of autonomous driving technologies.




Jamming occurrence simulation environment and results.

### ▶ Cloud-Based Data Processing Approach for GNSS Jamming Monitoring Technology

Jamming can be classified into unintentional jamming and intentional jamming. An example of unintentional jamming is the DME/TACAN system used to assist aircraft in landing near airports. Both intentional and unintentional jamming, characterized by powerful signal power, can be estimated using AOA and triangulation with few monitoring devices. However, monitoring environments affected by low-power jammers, such as the radio interference caused by a portable GPS jammer at Newark Airport in 2009, require a relatively large number of monitoring devices to be deployed, leading to high construction costs. Therefore, the Autonomous Navigation Lab at Inha University is researching cloud-based data processing approaches for efficient monitoring of weak signal jammers. This monitoring technology consists of a cloud server and multiple GNSS receivers within the monitoring area. The cloud server aggregates IF data received from GNSS receivers within the monitoring area and monitors jamming signals in the time-frequency domain using 2-D correlation. When jamming signals are detected, the type of jamming signal is identified based on its time-frequency characteristics, and information regarding signal strength is acquired to estimate the location of the jammer using TDOA techniques.

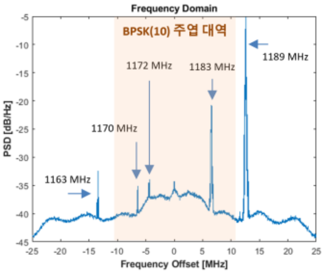


# GNSS/KPS RFI Monitoring and Analysis [TRL 4]

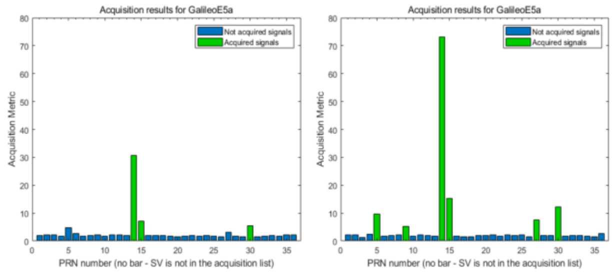
The planned KPS service bands, L and S bands, are shared with other services, and signals from these other services may cause interference to GNSS services. Therefore, to ensure the stable provision of KPS services in the future, it is necessary to analyze the interference impact caused by services considered as major interference sources in each band.

## ▶ L5 Band RFI Monitoring and Analysis

The L5 band corresponds to the frequency range of 1164 – 1215 MHz and is shared with the Aeronautical Radio Navigation Service (ARNS). Systems like DME/TACAN, which provide ARNS, transmit strong pulse signals in the L5 band, which can saturate the amplifiers of GNSS receivers, causing reception interference. While pulse blanking technology can mitigate the effects of pulse signals, the impact of ARNS on GNSS signal quality remains significant for receivers without pulse blanking capability. Therefore, research on the interference impact from ARNS is necessary for ensuring stable KPS services in the L5 band.



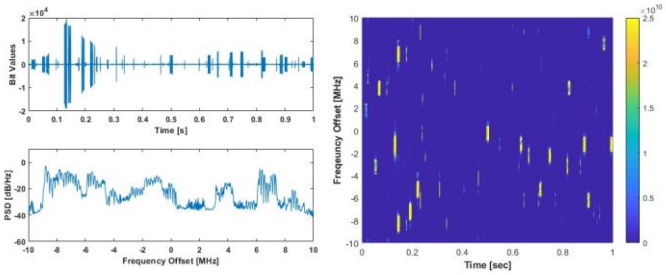

L5 band RFI monitoring



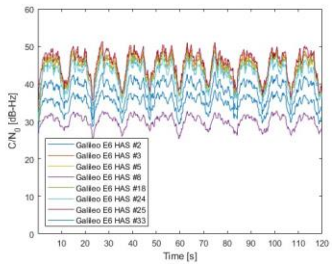

Galileo E5a signal acquisition results: PB not applicable(left), PB applicable(right)

## ▶ L6 Band RFI Monitoring and Analysis

The L6 band corresponds to the frequency range of 1260 – 1300 MHz and is shared by various services. Among them, Radio Location Service (RLS) is considered a major source of interference in the L6 band due to its higher priority compared to GNSS. Radar systems that use pulse signals are prominent examples of RLS, and their operation in the L6 band, characterized by strong transmission power, poses a significant risk of degrading GNSS signal quality. Moreover, as RLS is a ground-based service, interference analysis results from other regions cannot reliably predict the interference impact in KPS service areas. Therefore, research on interference impact analysis is necessary to assess the impact in the L6 band.



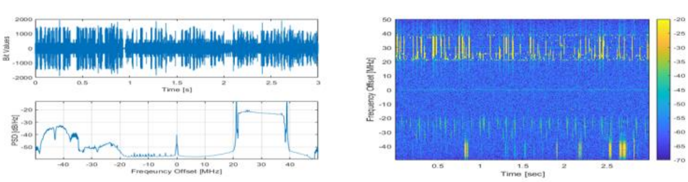

L6 band RFI monitoring: time/frequency (left), Spectrogram(right)



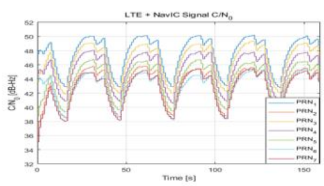

Galileo E6-B/C results: $C/N_0$

## ▶ S Band RFI Monitoring and Analysis

The S band corresponds to the frequency range of 2483.5 – 2500 MHz and is shared by various services. Adjacent to it are the ISM and LTE bands. Wireless data communication systems using ISM or LTE bands may emit out-of-band emissions due to their nature. Considering that the bandwidth allocated to the S band is relatively narrow at 16.5 MHz compared to other GNSS bands, emissions from adjacent bands could significantly degrade the quality of KPS services. Therefore, research on the interference impact from adjacent-band services is necessary to ensure stable KPS services in the S band.



S band RFI Monitoring



NavIC SPS signal processing results

## Features

### L5 Band Environment

- GNSS
  - (Worldwide) GPS/GLONASS /Galileo/BDS
  - (Regional) NavIC/QZSS
- Other Services
  - ARNS (e.g., DME/TACAN)
- Examples of DME/TACAN Channels in Korea:
  - 1170 MHz: Gimpo
  - 1172 MHz: Gimhae, Incheon
  - 1183 MHz: Yangju

### L6 Band Environment

- GNSS
  - (Worldwide) Galileo/BDS
  - (Regional) QZSS
- Other Service
  - RLS/EESS/Space Research /Amateur

### S Band Environment

- GNSS
  - (Regional) NavIC
- Other Service
  - FS/MS/MSS/RLS
- Adjacent Band
  - ISM: 2400 – 2483.5 MHz
  - LTE: 2500 – 2550 MHz

# Utilization of GNSS Technology in Space Environments [TRL 3 ~ 4]

## Features

### GNSS Signal Reception Environment Simulator

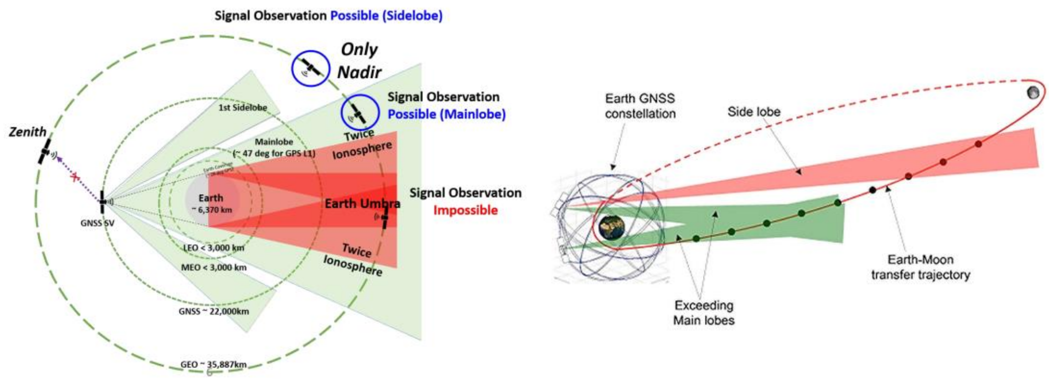
- Simulation of Various GNSS SSV Signal Reception Environments including GEO, Lunar Exploration Orbits, etc.
- Analysis of Reception Environment including Satellite Visibility, GDOP, Received Signal Power, Navigation Solution Errors, etc.
- Generation of Signal Parameters (Code Delay, Doppler, Carrier Phase, etc.) for Receiver Simulation.

### GNSS Receiver Simulator

- Signal Acquisition Unit Design and Testing (IF-level)
- Signal Tracking Unit Design and Testing (Semi-analytic, IF-level)
- Navigation Unit Design and Testing (LSE, KF)

## ▶ Space Service Volume (SSV)

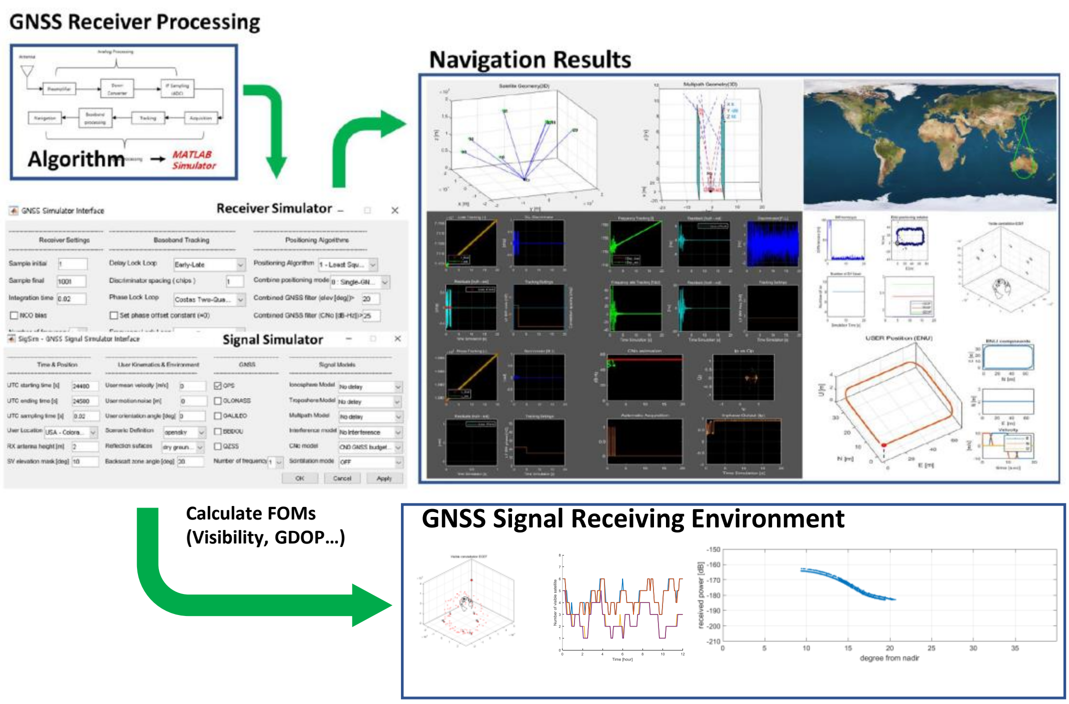
In missions involving deep space probes and orbit determination of satellites, accurate estimation of the precise position and velocity of fast-moving probes and satellites plays a crucial role in their operation. The space environment differs significantly in terms of signal reception from terrestrial GNSS systems, particularly at altitudes beyond Low Earth Orbit (LEO), where signals must be received from the opposite side of the Earth. Challenges include signal attenuation due to Earth obscuration and decreasing signal power as distance increases. Therefore, prior to developing GNSS receivers for space environments, it is essential to analyze the GNSS signal reception environment and redesign receiver parameters accordingly. Inha University's Autonomous Navigation Laboratory has the capability to analyze the GNSS signal reception environment of space exploration vehicles and design receiver parameters accordingly.




GNSS Signal reception environment in SSV

## ▶ GNSS Signal Reception Environment and Receiver Simulator for SSV

GNSS Signal Reception Environment and Receiver Simulator for SSV simulates various GNSS signal reception environments of the SSV and enables the design of optimal receiver parameters in those environments. As a signal reception environment simulator, it simulates reception environments for mission scenarios and designs receiver parameters for acquiring and tracking signals in the challenging reception environment of the SSV. By applying the designed parameters, the performance of the receiver can be evaluated.




SSV GNSS Signal reception environment/Receiver simulator

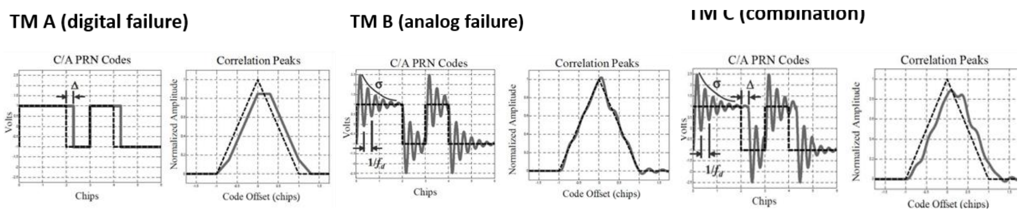
# GNSS Satellite Signal Error Monitoring and Modeling Technology [TRL 4]

## ▶ GNSS Signal Error Monitoring and Modeling

GNSS-based positioning services are increasingly utilized in various fields such as mobile phones, vehicles, and aviation. While the accuracy of precise positioning services has improved significantly due to extensive research, ensuring the reliability of measured information and monitoring errors is crucial for using location-based services. Therefore, there is a need for technology and systems capable of monitoring and modeling GNSS signal errors, including Evil Wave Form (EWF), Multipath (MP), and Radio Frequency Interference (RFI).

## ▶ Signal Quality Monitoring (SQM)

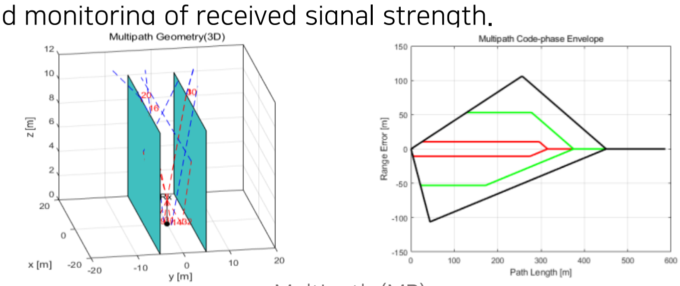
The signal quality monitoring system performs monitoring and detection of Evil Wave Form (EWF). EWF is caused by faults in the transmitter of GNSS satellite payloads and is broadly classified into three types. Threat Model (TM)-A and TM-B are caused by faults in the digital and analog components of the satellite payload transmitter, respectively, while TM-C corresponds to cases where both fault elements are combined. EWF is monitored using multi-correlator technology.




Evil WaveForm (EWF)

## ▶ Multi-Path Monitoring (MPM)

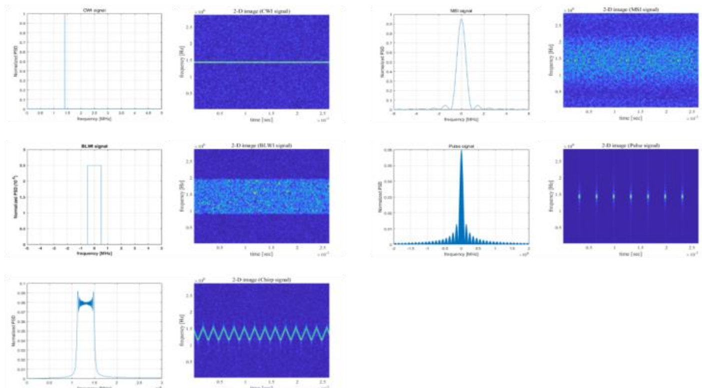
The multipath error monitoring system is responsible for detecting and analyzing multipath errors (MP). Multipath errors occur when GNSS signals are reflected off obstacles surrounding the receiver, resulting in both forward and backward scattering effects. These effects introduce errors in the pseudorange calculated by the receiver. Multipath errors are detected using techniques such as code-minus-carrier comparison and monitoring of received signal strength.




Multipath (MP)

## ▶ Radio Frequency Interference Monitoring (RFIM)

The radio frequency interference (RFI) monitoring system performs the monitoring and detection of RFI. RFI can be broadly classified into five types: Continuous Wave Interference (CWI), Matched Spectrum Interference (MSI), Band Limited White Interference (BLWI), pulsed interference, and chirp interference. The system utilizes effective Carrier-to-Noise Density (C/N0) to detect RFI.



Radio Frequency Interference (RFI)

# Features

## GNSS Signal Error

- Evil Wave Form (EWF)
- Multipath (MP)
- Radio Frequency Interference (RFI)

## EWF Modeling

- TM-A, TM-B, TM-C Modeling
- Apply error to the I/Q correlator outputs
- Delta chips, dampling factor, damping frequency, EWF mode

## MP Modeling

- Modeling multipath (MP) based on the LMS model or geometry model,
- Incorporating errors into pseudorange and C/N0
- Antenna height, LMS mode, obstacle type, reflection surface, backscattering zone angle, MP scenario

## RFI Modeling

- Modeling 5 types of Radio Frequency Interference (RFI)
- Incorporating errors into pseudorange and C/N0
- Setting parameters such as jamming mode, jamming bandwidth, J/S, and specific parameters for each RFI.

# Features

## COSPAS-SARSAT

- Disaster rescue communication support program
- Signals emitted by the beacon are relayed through multiple satellites and received at the LUT
- The LUT can estimate the beacon's location without prior information.

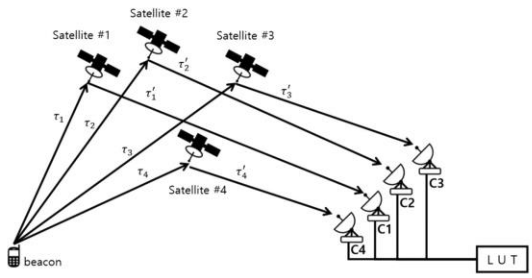
## Simulator

- Generation of COSPAS-SARSAT 2nd generation beacon-emitted signals using GNSS satellite orbit information supported by COSPAS-SARSAT
- Calculation and application of signal components using the orbit information of GNSS satellites supporting COSPAS-SARSAT
- Calculation of TDOA and FDOA using the generated signals and beacon location estimation based on NLSE. Flexibility in specifying beacon and LUT locations
- Availability of GPS, GLONASS, Galileo, and KPS usage during simulation. Utilization of brute force, FFT-IFFT, coarse-fine, BIS, and MLE algorithms during TDOA and FDOA generation
- Configuration of signal parameters such as C/N0, sampling frequency, accumulation time, etc
- Output of measured BER and final location estimation results during signal processing.

# Location Estimation Technology for COSPAS-SARSAT [TRL 3]

## ▶ COSPAS-SARSAT

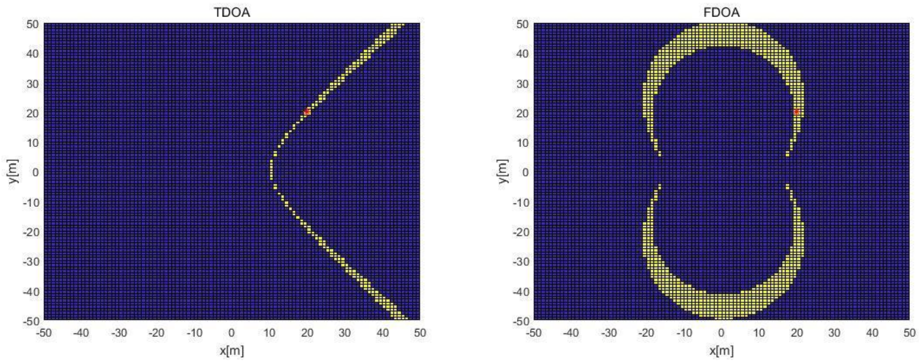
COSPAS-SARSAT is a disaster relief communication support program aimed at individuals or aircraft, ships, etc., in distress activating 406 MHz beacons to transmit search and rescue signals to national and institutional authorities. The signals emitted by the beacon are relayed through multiple satellites and received at the LUT. Typically, when the beacon emits a signal, it includes its location information in the message, but due to various causes such as defects in the GNSS receiver mounted on the beacon, the location of the beacon may not be known. In such situations, the LUT should be able to estimate the location of the beacon using the received signals.




COSPAS-SARSAT System

## ▶ Beacon Location Estimation Techniques

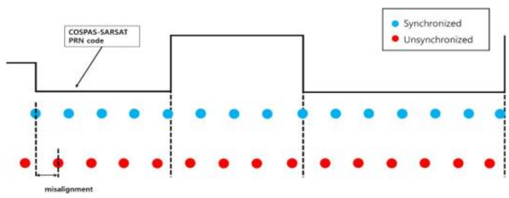
The signals emitted from the beacon are received through satellites with different geometric arrangements, resulting in each signal having different code delays and Doppler frequencies. The LUT utilizes these code delays and Doppler frequencies to estimate the beacon's position using differential TDOA and FDOA measurements.



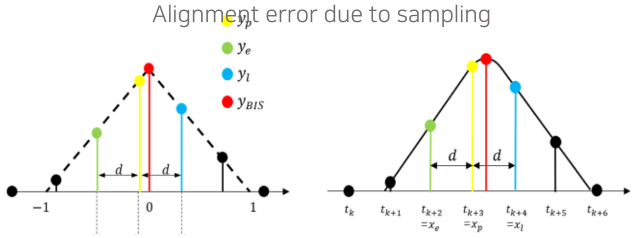

Location Estimation based on TDOA/FDOA

## ▶ Improvement Algorithms for Position Estimation

When using a low sampling frequency in the LUT, the alignment error between the two signals increases, leading to decreased performance in the final position estimation. To address this issue, the Block Interpolation-based Synchronization (BIS) algorithm has been proposed to calculate the reference values of the correlator outputs with alignment errors. By utilizing the BIS algorithm, the LUT achieves high position estimation performance even at low sampling frequencies.




Alignment error due to sampling

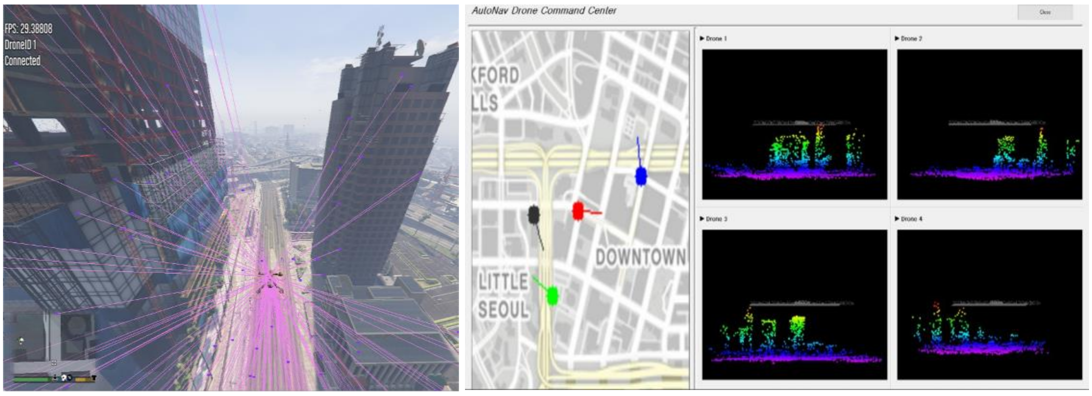


Error solving by BIS algorithm

# Driving Simulator based UAM Localization [TRL 3 ~ 4]

## ▶ Multi-User UAM Simulator

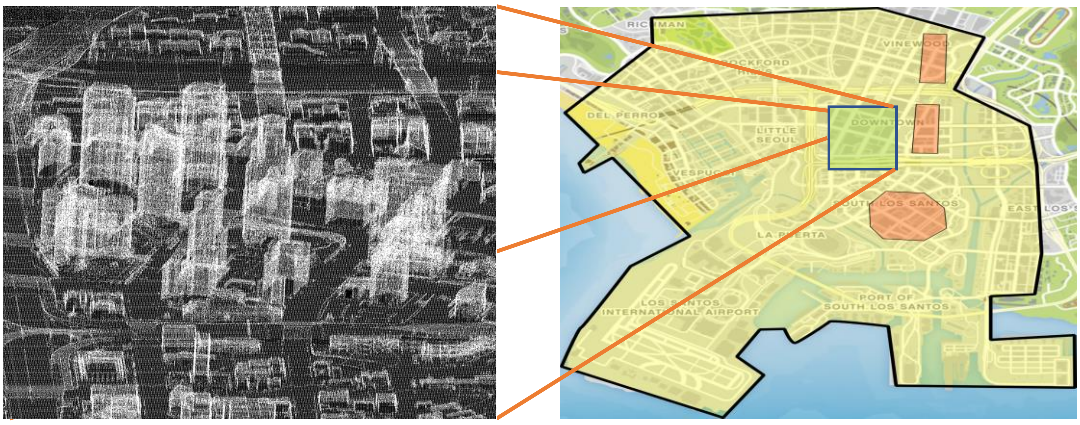
Utilizing a driving simulator, a Multicast Socket is implemented to enable communication among users, aiming to establish a multi-user connection environment. This Multicast Socket is integrated into the UAM Simulator by adding it to the game engine's internal workings. Each user transmits their ID, Position, and Quaternion information to all users within the group every frame. Leveraging this setup, other users' UAMs are modeled within one's simulation environment, facilitating the creation of a multi-user environment.




Multi-User UAM Simulator

## ▶ HD Map using LiDAR Point Cloud

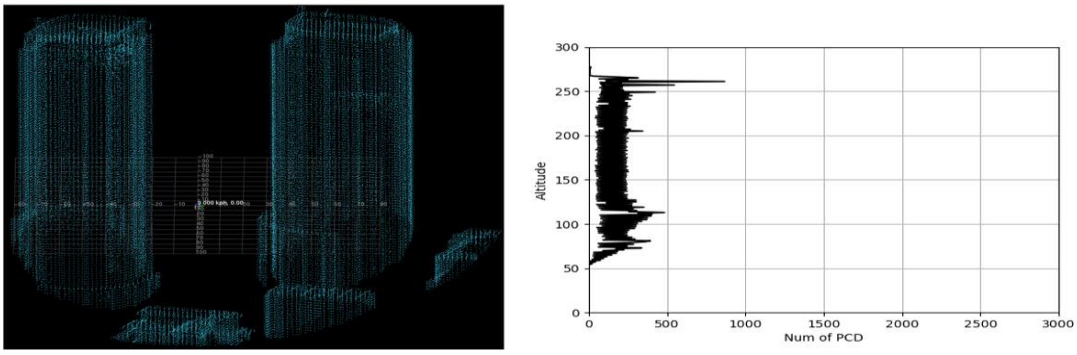
Using a LiDAR sensor, 3D point cloud data is collected and processed to generate a global map. Through this process, UAMs can identify their positions using Descriptors in various environments. The generated HD map is efficiently managed by maintaining high resolution while Down-Sampling.



LiDAR Point Cloud Map Data Base

## ▶ Global Localization using HD-Map and LiDAR

Using Point Cloud Data (PCD) from LiDAR sensors, we identify key features of the surrounding environment. Based on these features, we estimate odometry or determine location through loop closure to recognize previously visited areas. To estimate position accurately in the extensive HD map, we employ effective Descriptors for rapid exploration, enabling precise localization in the 3D environment.




UAM PCD Descriptor at Altitude 200m

## Features

### Multi-User UAM Simulator

- Configuring a Multi-User Environment with Multicast Sockets
- Implementing a Research Environment for Attitude Control and Position Estimation in UAMs

### HD-Map using LiDAR Point Cloud

- 3D Point Cloud Data
- HD-Map

### Global Localization

- Odometry
- Descriptor
- Locate Estimation

인하대학교 INHA UNIVERSITY

AUTONOMOUS NAVIGATION LAB

## Features

### Autonomous Driving

- Deep learning-based traffic light recognition
- Deep learning-based nearby vehicle recognition
- Front vehicle detection and distance recognition
- Precision positioning based on RTK services
- Cross-validation and reliability with GPS/INS
- V2X service-based vehicle positioning

### Autonomous Driving Service

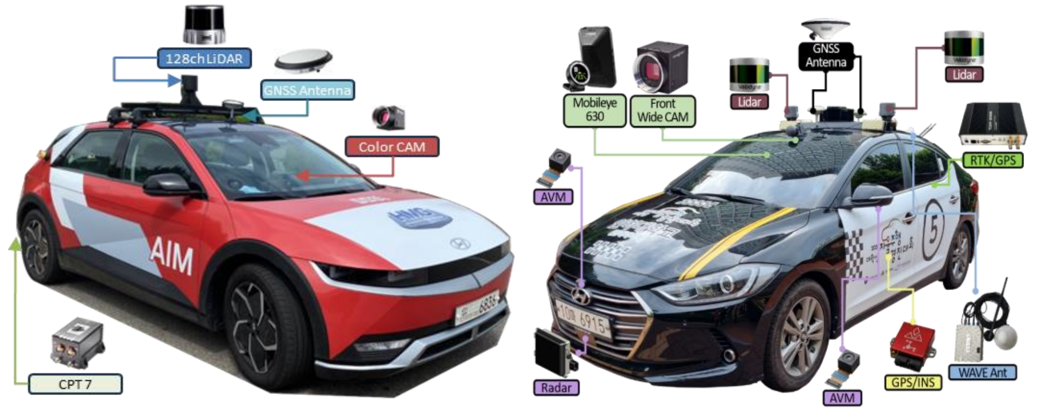
- Developing service platform algorithms for service delivery (performing and delivering services)
- Electric vehicle-based unmanned autonomous robot (ERP-42)
- Deep learning-based environmental variable recognition
- Precision positioning based on RTK service
- Installation of emergency braking system to ensure stability
- Precise vehicle control using inertial navigation system

# Research on Real Autonomous Driving Technologies and Services [TRL 4]

### ▶ Autonomous Driving Technologies based on Real car

Autonomous driving technology is divided into the recognition field, which recognizes the surrounding environment and vehicle status with sensors such as GPS, IMU, camera, lidar, radar, ultrasonic, and V2X installed on the vehicle; the judgment field, which processes and analyzes the information received from the sensors to determine the movement of the vehicle; and the control field, which controls commands based on the judgment and adjusts the speed and direction of the vehicle.

Inha University's Autonomous Navigation Lab is developing autonomous driving technology using real autonomous vehicles and sensors. In the recognition field, we recognize the surrounding environment through deep learning-based algorithms using one front camera, two lidar, and one mobile eye camera. We are also developing GPS/INS integrated navigation algorithms and positioning algorithms using V2X services. In the area of judgment and control, we have implemented ADAS (Advanced Driver Assistance Systems) functions such as automatic lane change, forward collision prevention, and following distance maintenance.

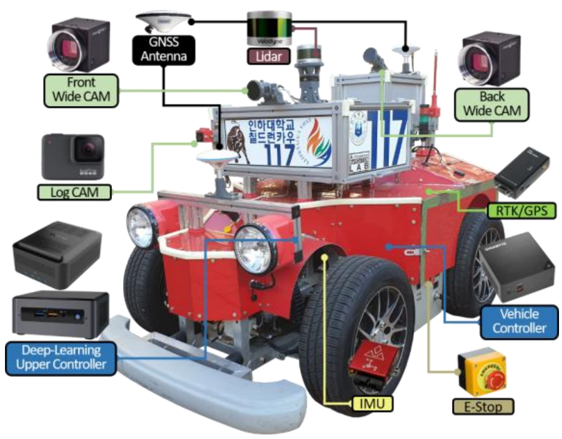



Autonomous experimental car (IONIQ5, Avante)

### ▶ Autonomous Delivery Service Technology based on Unmanned Platforms

Autonomous driving technology is a key technology and a major business model that will lead future markets. Particularly, delivery and logistics business models using autonomous driving technology are future service markets attracting attention. To implement such autonomous driving-based services, it is necessary to identify the response factors required for the service in advance and secure safety reliability.

Inha University's Autonomous Navigation Laboratory is researching delivery services using autonomous driving through electric vehicle-based unmanned robots. To complete the delivery service, we have developed an algorithm that judges the situation in real time according to the current location, and if an obstacle is found on the driving route while delivering to the destination, it avoids it and creates a new route to the designated destination. We are conducting research on autonomous driving-based delivery service technology that is highly reliable while responding to various situations.



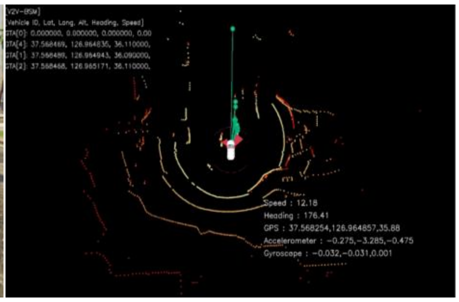

Electric vehicle-powered autonomous experimental robots

# Autonomous Driving Simulator [TRL 5]

## ▶ Autonomous Driving Simulator based on a Commercial Game Engine

The autonomous driving simulator developed by Inha University's Autonomous Navigation Lab is a simulator developed based on a commercial game based on the RAGE physics engine, and is configured as an environment where recognition, judgment, and control algorithms required for autonomous driving systems can be experimented with and evaluated in a high degree of freedom. GPS, IMU, camera, lidar, radar, and ultrasonic sensors mounted on actual autonomous vehicles are modeled, and a V2X communication environment is implemented to enable research on C-ITS services. Based on this, it is possible to build datasets required for autonomous vehicles and design deep learning networks.

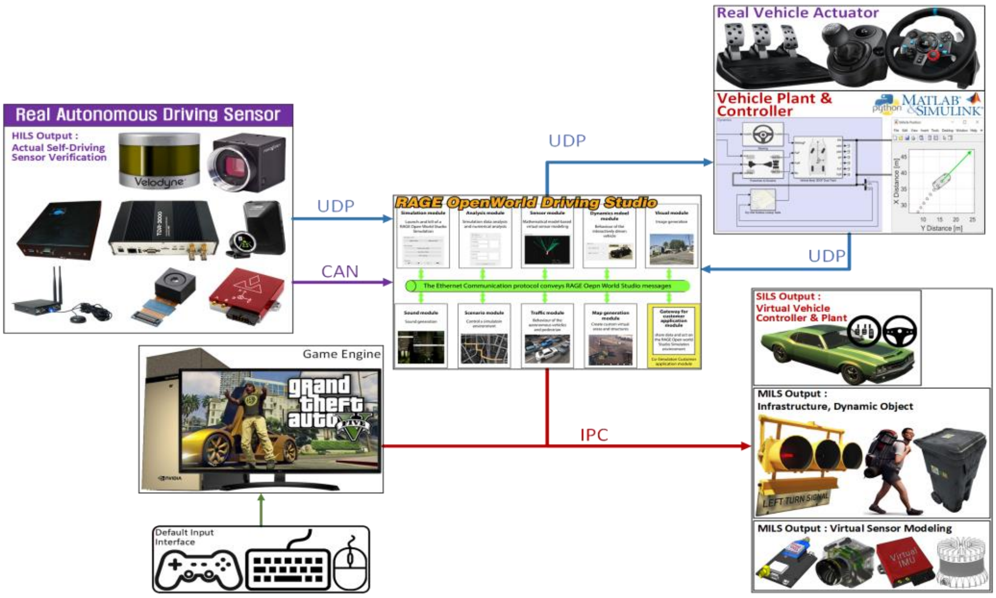
Autonomous driving simulator based on a commercial game engine



Lidar sensor modeling GUI

## ▶ SILS/VILS/HILS based on Autonomous Driving Simulators

Many commercially available autonomous driving simulators are used to study actual autonomous driving systems, but there is a gap between them and the real world. Inha University's Autonomous Navigation Lab has implemented Software-in-the-Loop Simulation (SILS), Hardware-in-the-Loop Simulation (HILS), and Vehicle-in-the-Loop Simulation (VILS) based on autonomous driving simulators to reduce the gap between the two environments. SILS is a system that evaluates the performance of software in an autonomous driving simulator, and HILS is a system that evaluates the performance of actual hardware mounted on an autonomous vehicle in an autonomous driving simulator. VILS is a system that directly connects an autonomous vehicle to an autonomous driving simulator to evaluate its performance. Inha University's Autonomous Navigation Laboratory has configured a GNSS HILS system using a GNSS signal generator, and is conducting research to reduce the difference between virtual and real environments by building a VILS system by connecting a small electric vehicle and an autonomous driving simulator.




SILS/HILS/VILS System

# Features

## Autonomous Driving Simulator Based on a Commercial Game Engine

- Experimentation environment for high-degree-of-freedom autonomous driving systems
- Sensor modeling and V2X communication environment for autonomous vehicles
- Functional design of judgment and control algorithms
- Designing deep learning networks for autonomous driving
- Utilize various mobility applications other than vehicles

## SILS/HILS/VILS

- Vehicle Actuator Control
- GNSS HILS System Implementation (GNSS Signal Generator, U-Blox Module & RTK)
- Implementation of VILS system using small electric vehicle

# GPS-HILS based on Driving Simulation [TRL 5]

## Features

### GPS-HILS

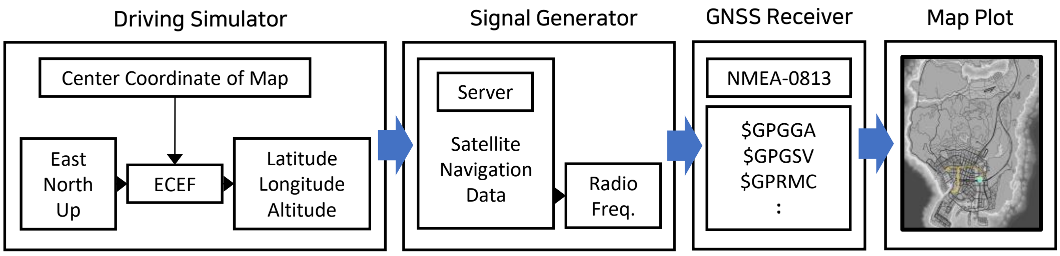
- Creating a realistic GPS signal environment with HILS
- Research environment for jamming and spoofing

### Radio Interference Scenario with HILS

- Jamming
- Spoofing
- Meaconing

### ▶ GPS-HILS

To realize a realistic simulation environment, you can consider Hardware-in-the-Loop Simulation (HILS), which connects real hardware to the simulation. Among them, GPS-HILS for GPS signal reception is implemented by connecting a signal generator and receiver to the simulator. The GPS signal in the simulator's own coordinate system is converted to the actual signal by performing coordinate system conversion, and then the GPS signal is transmitted. The receiver receives the transmitted signal and displays the location on the map to check the behavior of the GPS system. By adding the process of generating and receiving signals outside of the simulation, you can generate data like real GPS signals and configure scenarios such as jamming or spoofing.

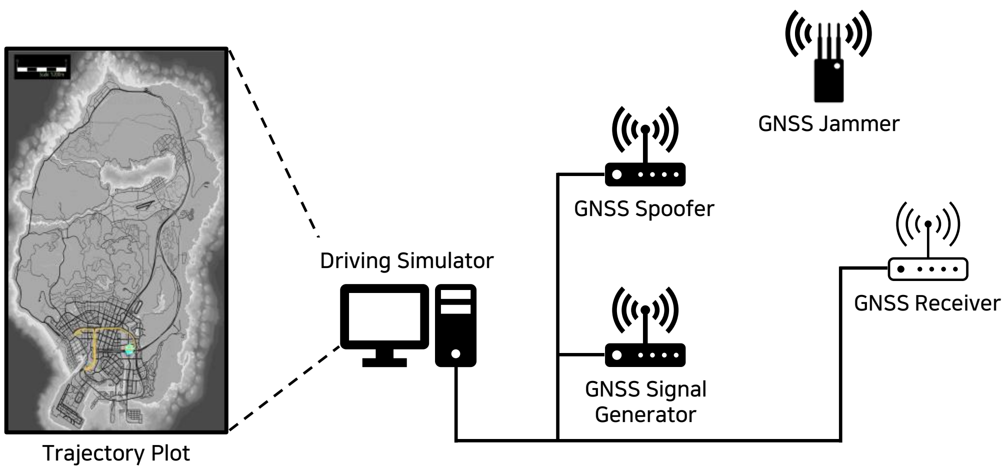



GPS-HILS Diagram

### ▶ Configuration of Signal Interference Scenario using GPS-HILS

Autonomous vehicles that rely heavily on satellite navigation are vulnerable to attacks on GPS signals, including jamming, which involves emitting high intensity noisy signals that interfere with the reception of GPS signals, and spoofing, which involves generating signals with different location information. We used GPS-HILS to experiment with such scenarios in a driving simulator.

Based on the Ground Truth (GT) of the autonomous vehicle in the simulator, we can send GPS information through a signal generator while simultaneously sending a deceptive signal modulated by a spoofing algorithm through an additional signal generator. This allows us to create a spoofing scenario by implementing a situation where a real signal and a spoofed signal are simultaneously applied to the signal receiver, creating an environment in which we can conduct research on spoofing. We can also create a jamming scenario where the generated GPS signal is blocked by the jammer.




GPS-HILS Architecture based on driving simulator

# Unlimited Autonomous Driving Data Generation and Learning Technology [TRL 4]

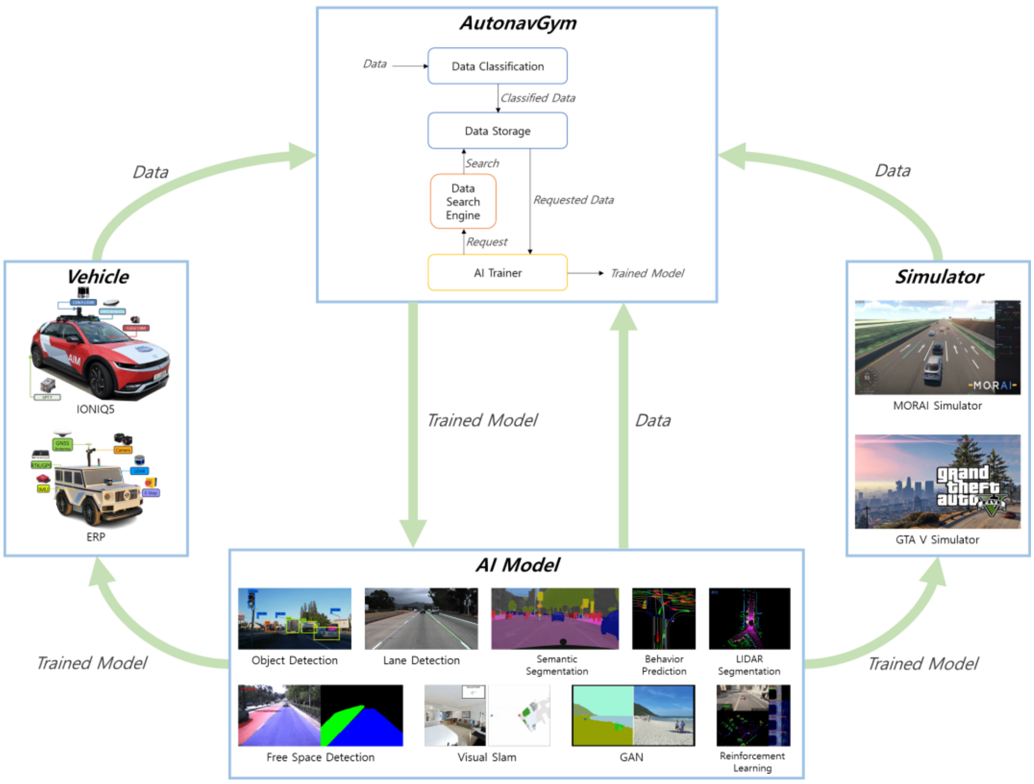
## ▶ Create Unlimited Data

Autonomous driving simulators based on game engines and commercial simulators can generate an unlimited autonomous driving data. Particularly, by configuring a multi-user access environment, it is possible to generate data for critical and edge cases that are difficult to experiment in real life. Inha University's Autonomous Navigation Lab generates data for various scenarios and develops safer and more reliable autonomous driving algorithms based on it.


Configure multi-user access environments and create critical scenarios

## ▶ AutonavGym

AutonavGym is an autonomous driving AI automatic learning platform built by Inha University's Autonomous Navigation Lab. It automatically performs training and improvement tasks of autonomous driving AI models by utilizing data from real vehicles along with unlimited data generated by utilizing a multi-user access autonomous driving simulator. Particularly, it utilizes Semi-supervised learning and Auto Labeling technologies to effectively utilize data, and through this process, it generates autonomous driving AI models with excellent performance and stability.




AutonavGym System

# Features

## Create Unlimited Data

- Utilizing the Multi-User Access Simulator
- Create critical and edge case scenarios
- Generate unlimited sensor and driving data

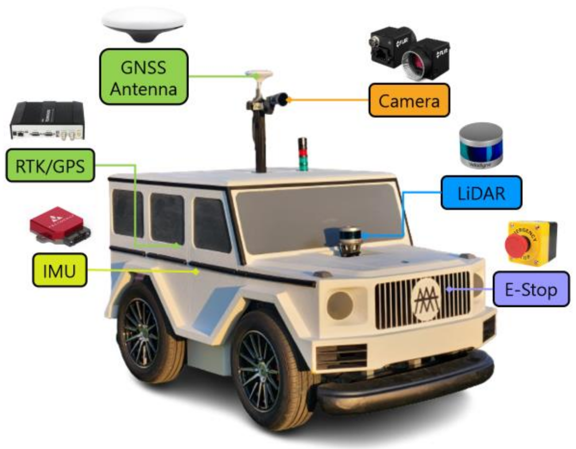
## AutonavGym

- Utilizing simulator data and real-world data
- Automatically Train Autonomous AI Models
- Perform semi-supervised learning and auto-labeling to leverage data

# Autonomous Driving Research and Development (Supporting Undergraduate Interns) [TRL 2 ~ 3]

## ▶ Inha University's Undergraduate Autonomous Driving R&D Club

The A.I.M Team, an autonomous driving research and development club formed in 2021 with the support of various organizations on campus, including Inha University's Startup Support Group, Student Support Team, and the Student Government Association, is engaged in various research and development projects led by undergraduate students. Starting with the 'Field-Linked Future Leading Talent Fostering Support Project' supported by the National Research Foundation of Korea, the team has participated in various R&D projects, including the 'Active Fire Monitoring and Smart Driveway System Based on Autonomous Driving Service' of the 'Smart Campus Challenge' and the 'International University Student Creative Car Autonomous Driving Contest'. In 2022, we started collaborating with the Georgia Institute of Technology in the U.S. to conduct various projects to improve the R&D capabilities of undergraduate students.





A.I.M, Inha University's autonomous driving R&D club

## ▶ Centralized Fire Protection Services for Smart Campuses

Autonomous driving is a major business model and a key technology that will lead the future market. Based on autonomous driving technology, existing human-centered businesses are being replaced by autonomous driving technology, and services using autonomous driving technology have infinite scalability as 24-hour services using unmanned robots become possible.

Through the 'Smart Campus Challenge' conducted by the Ministry of Land, Infrastructure, and Transport and the Korea Agency for Infrastructure Technology Advancement (KAIA) in 2021, undergraduate students at Inha University were tasked with building an active fire monitoring and smart driveway system based on autonomous driving services. Based on the connection with Inha University's central situation room, autonomous unmanned robots patrol the campus and identify fire situations. At the same time, it detects illegally parked vehicles so that fire trucks can enter the campus as soon as possible in case of a fire to secure golden time. The autonomous unmanned robots are equipped with multiple cameras so that personnel in the central control center can check and respond in real time. Through this, the robot is scalable to provide not only fire protection but also crime prevention services.

# Features

## Autonomous Driving R&D

- Undergraduate-led R&D team
- Working on a variety of autonomous driving research projects
- Ongoing collaboration with Georgia Institute of Technology

## Autonomous Centrally Controlled Fire Disaster prevention services

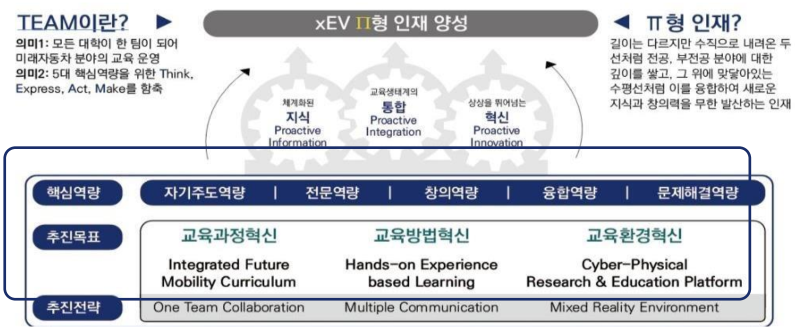
- Using unmanned autonomous robots
- Establishing a centralized control system with a connected CIC24-hour campus patrols using unmanned robots
- Cracking down on illegal parking on campus
- Determining fires using artificial intelligence
- Emergency evacuation broadcast in the event of a fire disaster
- Quick decision-making by centralized control personnel through real-time video

# Workforce Development (R & E)

▶ Ministry of Trade, Industry and Energy (MOTIE) Future Automotive Core Technology Specialist Training Program


▶ Ministry of Trade, Industry and Energy Embedded System Manpower Training Project


▶ Ministry of Education Phase 4 BK21 Project ICT-Future Automotive Convergence Education Research Center


## Features

### Developing future automotive professionals

- Organizer : Korea Electronics & Telecommunications Industry Promotion Association
- Period : 2022.03~2027.02
- Purpose: Fostering master's and doctoral R&D manpower through ICT-based future automobile industry degree programs, industry-academia collaborative projects, and on-site practical training

### Developing a specialized workforce for industrial convergence embedded systems

- Organizer : Korea Information Industry Association
- Period : 2021.03~2026.02
- Purpose : Fostering advanced manpower for new industry convergence-type embedded system based on artificial intelligence technology to secure global technology competitiveness
- Participating Institutions : Inha University, Korea Electronics Technology Institute, etc.

### BK21 Project ICT-Future Automotive Convergence Education Research Center

- Organizer : Inha University
- Period : 2020.09~2027.08
- Purpose : Global Autonomous Innovation Education and Research Center to foster experts in ICT-based future automobile convergence core technologies and lead cutting-edge research

### Department of Education Digital Sharing Initiative

- Organizer : Kookmin University
- Period : 2022.05~2027.02
- Purpose : Presenting new standards for future automotive higher education system and fostering innovative talents for future automobiles

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