



**Development of precise docking system contributing  
to Next Generation Transportation in SIP**

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# INDEX

A vertical decorative image on the left side of the slide. It features a dark background with vibrant, multi-colored light trails (yellow, orange, blue, purple) that suggest motion and technology, possibly representing a road at night or a futuristic environment.

- 1. Next generation transport in SIP**
- 2. Precise docking control technology**
- 3. Sensor fusion technology**
- 4. Cooperative docking control with driver**
- 5. Field operational test**

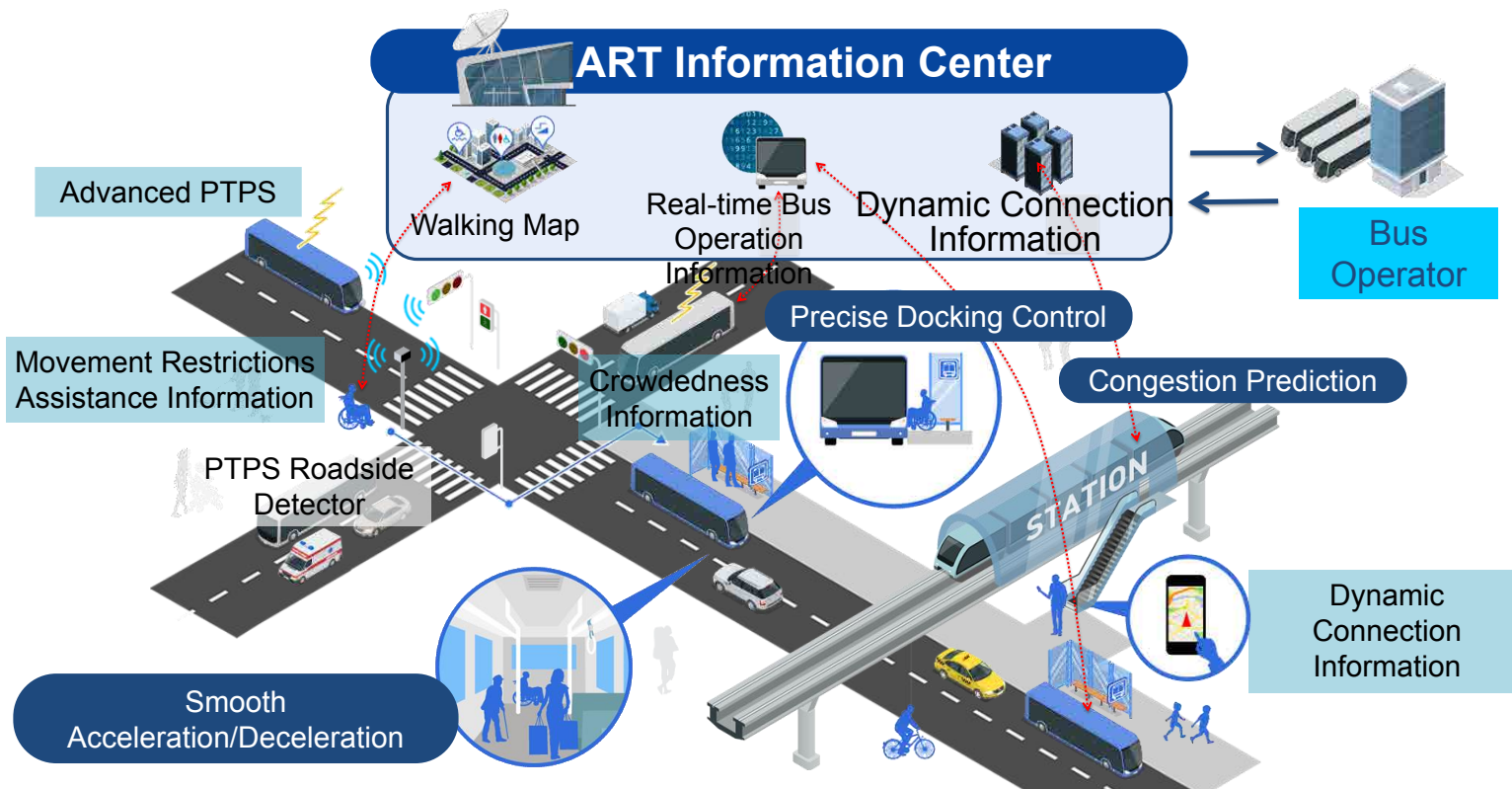
1

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# Next generation transport in SIP

# Next Generation Transport in SIP



*Realize consistent accessibility for all people including elderly and handicapped person*

# Next Generation Transport in SIP



2

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## **Precise docking control technology**

# Development of sensing and control technology for ART docking system



- > Sensor fusion technology : Vehicle position, surroundings (pedestrian, bicycle and others)
- > Control technology : Integrated control of steering and braking

## Target

### ① Smooth embarkment at station



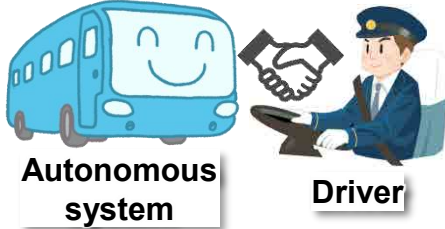
### ② Robust control in various environments



### ③ Smooth braking and steering control



### ④ Cooperative docking control with driver



## Development item

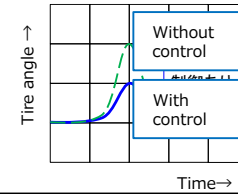
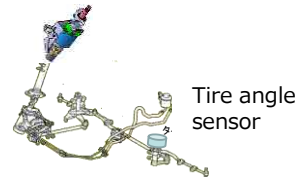
## Technology

### 1) Sensor fusion technology compatible with current road marking



- > Robustness in various environments
- > Small infrastructure investment
- > Fast image processing

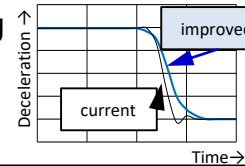
### 2) Improvement of steering system control performance



- > Advanced steering control reducing dead band or delay caused by mechanical issue

### 3) Reducing jerk at braking and cornering

- > Sophisticated and integrated steering and braking control



### 4) Harmonizing driver and automated operation

- > Precise estimation of driver intention from steering torque or deviation of steering torque

# ITS Asia-Pacific forum Fukuoka

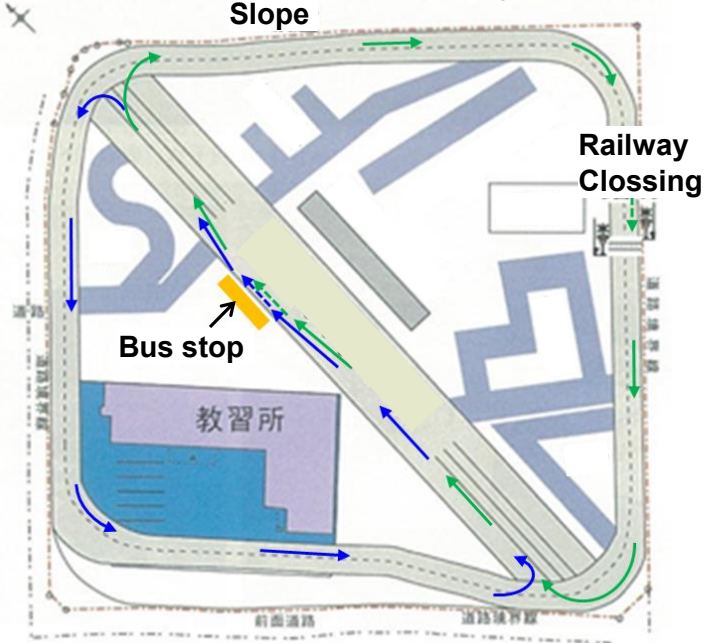
Technical visit

Training center of Nishitetsu bus

May 8-10th, 2018

About 120 Participants

Autonomous driving and precise docking  
at closed course with RTK-GPS sensing



Course for demonstration







# Development at The University of Tokyo

The University of Tokyo

ITS R&R Experiment Fields at Kashiwa

Demonstration at October 16th, 26th, 27th, 2018

Over 500 Participants

Autonomous driving and precise docking  
at closed course with RTK-GPS sensing



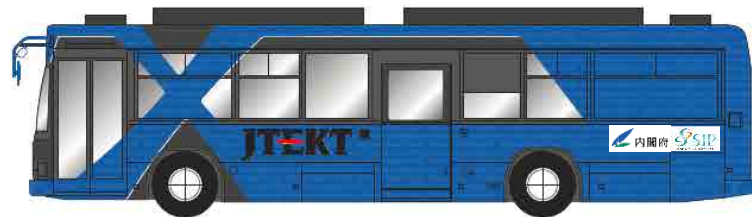
# Test mule for precise docking control

## Specification

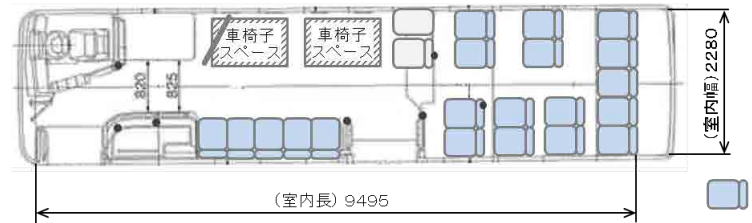
- Blue Ribbon City (Hybrid)/Hino motors, Ltd
- Number of seats : 20
- Attachments for wheel chair : 2
- Length:10.5m×Width:2.5m×Height:3.3m
- Number of doors : 2
- Height of floor : About 340mm (Non step)

## Additional equipment

- Autonomous steering actuator
- Autonomous brake actuator
- GNSS、QZSS receiver
- Front and side camera
- Lidar



Appearance



Seat layout

Seat

# Optimization of control gain

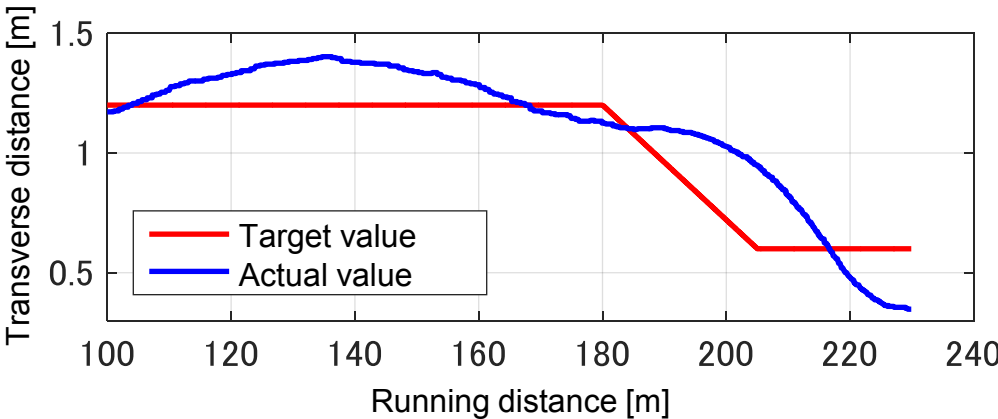
Control gain  $k_2$  (term of decreasing transverse deviation)

$k_2$  value was Constant  $\rightarrow$  Switch  $k_2$  values (straight / docking)

$\Rightarrow$  Optimum vehicle behavior in each situation

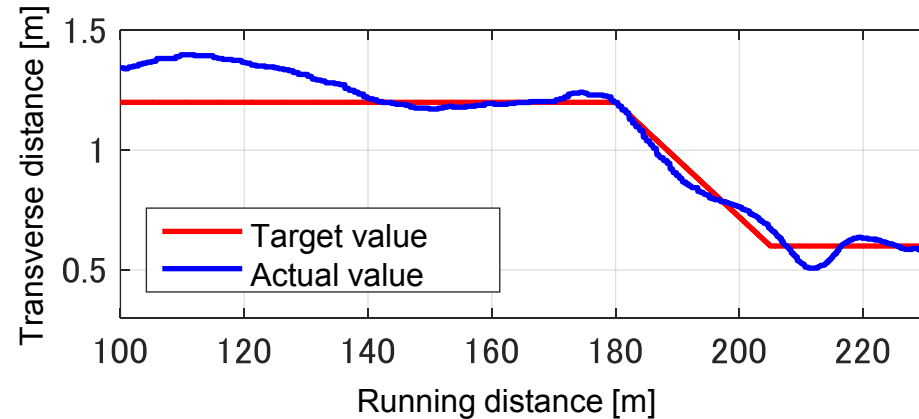
Constant

Optimized gain in straight situation.



Switching (straight / docking)

Optimized gain in each situation.



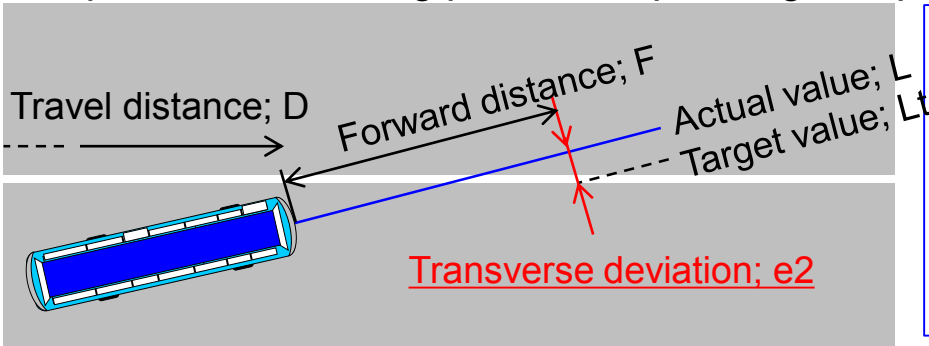
# Optimization of calculating transverse deviation

## Transverse deviation

① Change calculating position (vehicle forward) for target value.

(Last year, calculating position for actual value was already changed.)

② Optimize calculating position depending on speed, situation (straight/ docking).

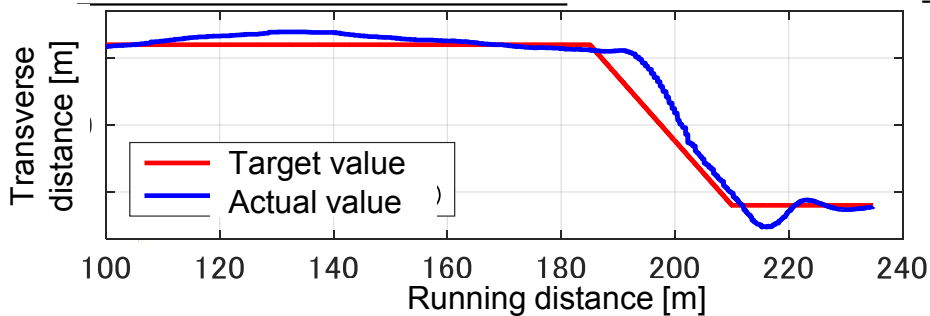


$$e2 = Lt(D + F) - L(D + F)$$

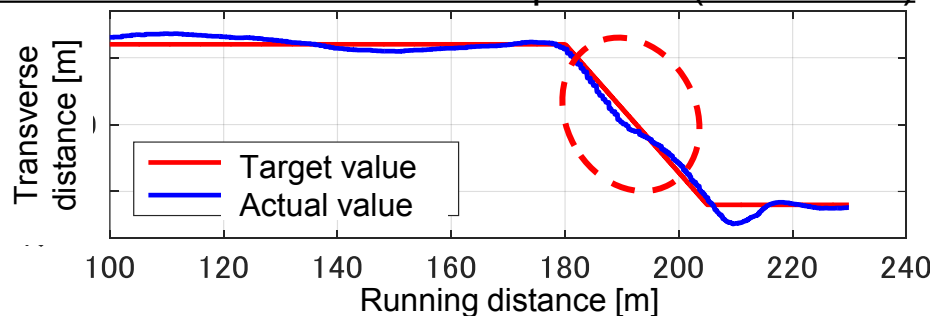
Transverse deviation  
Target value  
Travel distance  
Distance between actual calculating position and value vehicle front

## Effect of changing calculating position (target value)

### Calculated at vehicle front



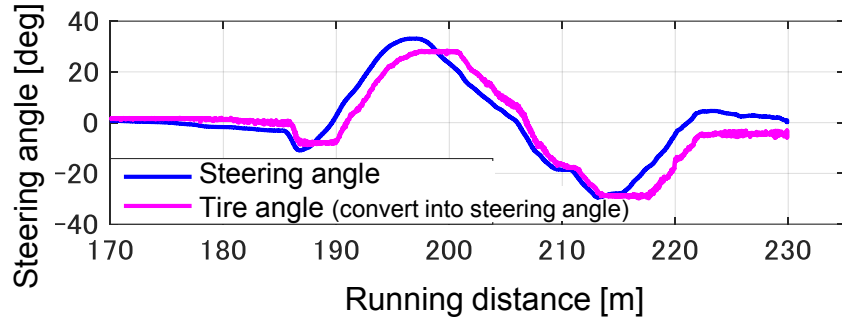
### Calculated at vehicle forward position (distance F)



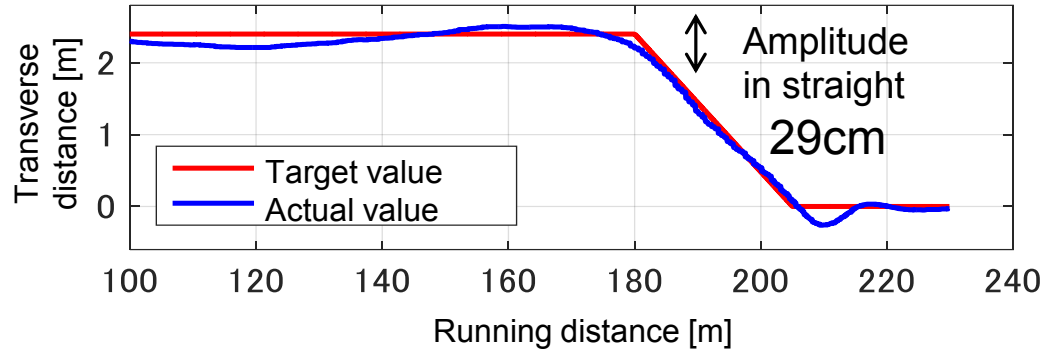
# Steering control which compensate the tire angle response to the steering angle behavior

Dead zone between steering angle and tire angle is about 11degrees.

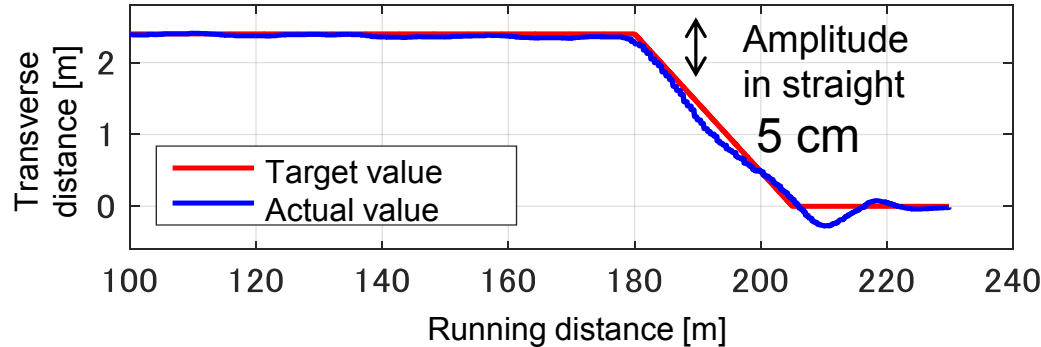
⇒ Correct target steering angle.



## Without compensation



## With compensation



# Stop to the bus stop with high accuracy

## Braking control method

- Calculate target acceleration using assumed stop point.

※  $a$ : target acceleration,  $v$ : velocity

$$a = \frac{v^2}{2(St - S)}$$

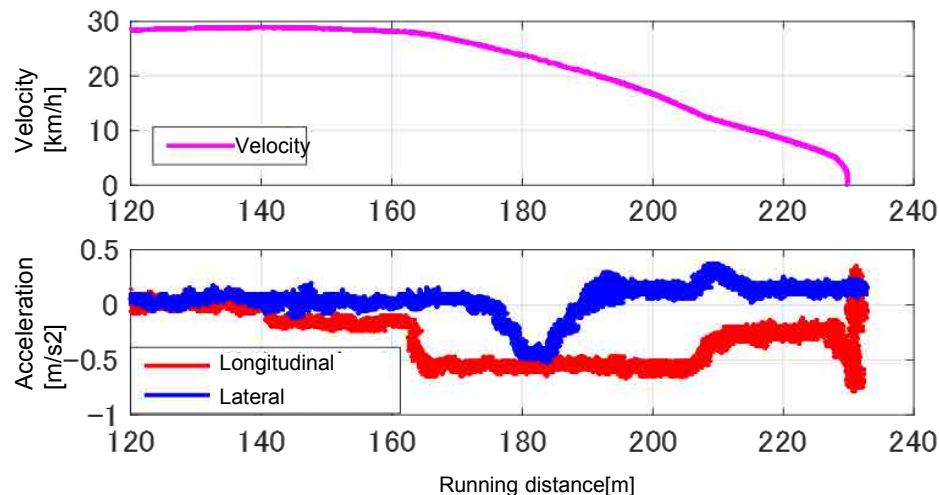
$S$ : running distance,  $St$ : assumed stoppingpoint

- Set different values of assumed stop point in the first half and the latter half of lateral moving

## Result

Longitudinal deviation:  $\pm 0.2\text{m}$

※ Allowable range:  $\pm 0.5\text{m}$ .



# Precise docking control (Driver's view)





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# Sensor fusion technology

# Sensor fusion technology



## Comparison of RTK-GPS / Front camera

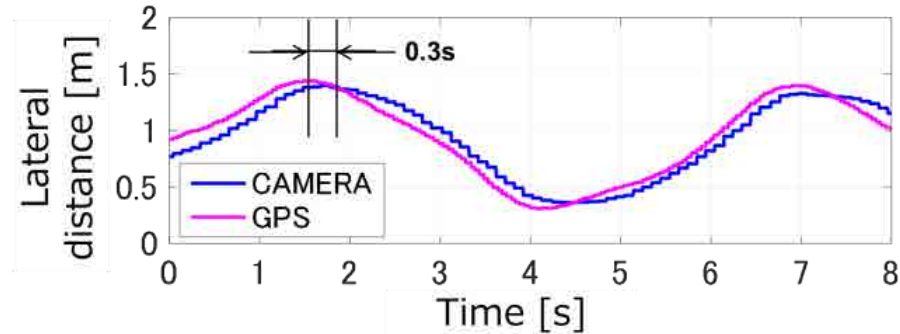
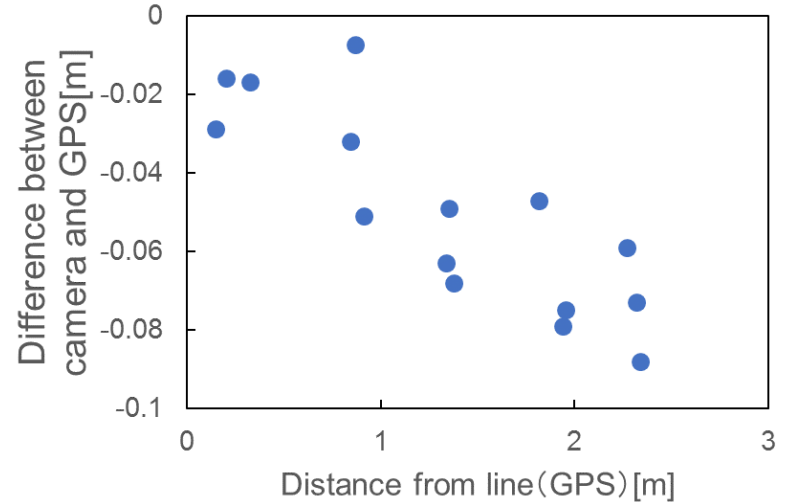
Fundamental study for multiple sensing method selection or cooperation is progressed.

Output value of lateral position is different between RTK-GPS and front camera.

It is related to the actual distance.

The value from camera is delayed to the value from RTK-GPS (0.3sec)

When the sensor switches, it should be taken into account for sensor characteristics.



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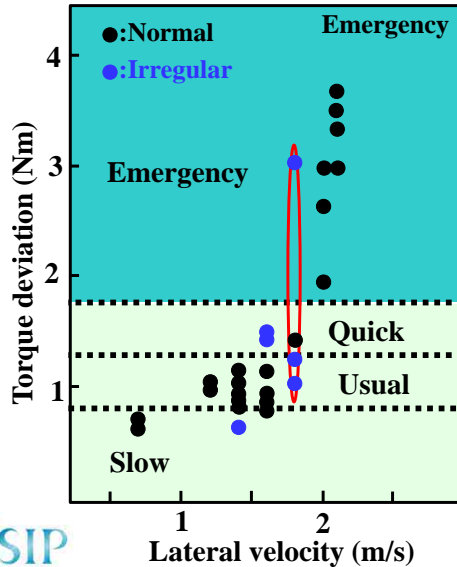
## **Cooperative docking control with driver**

# Cooperative docking control with driver

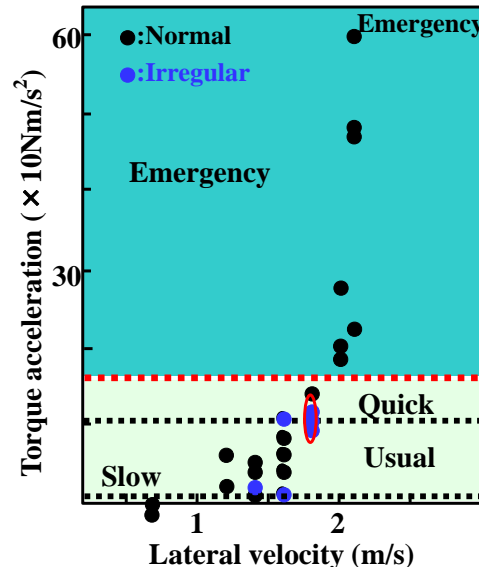


Sharing control method between vehicle system and driver  
is developed using Steer-by-wire system without mechanical linkage

In the case of avoidance at emergency on level 3,  
additional function to autonomous avoidance will be possible  
by precise estimation method of driver's intention from steering internal parameter.



(a) Torque deviation



(b) Torque acceleration

Example ;  
Estimation of driver intention  
from the deviation of  
steering torque or torque acceleration

JSAE journal  
Vol.31, No1, January 2000.  
20004035

# Intervention by driver (Avoidance at emergency)



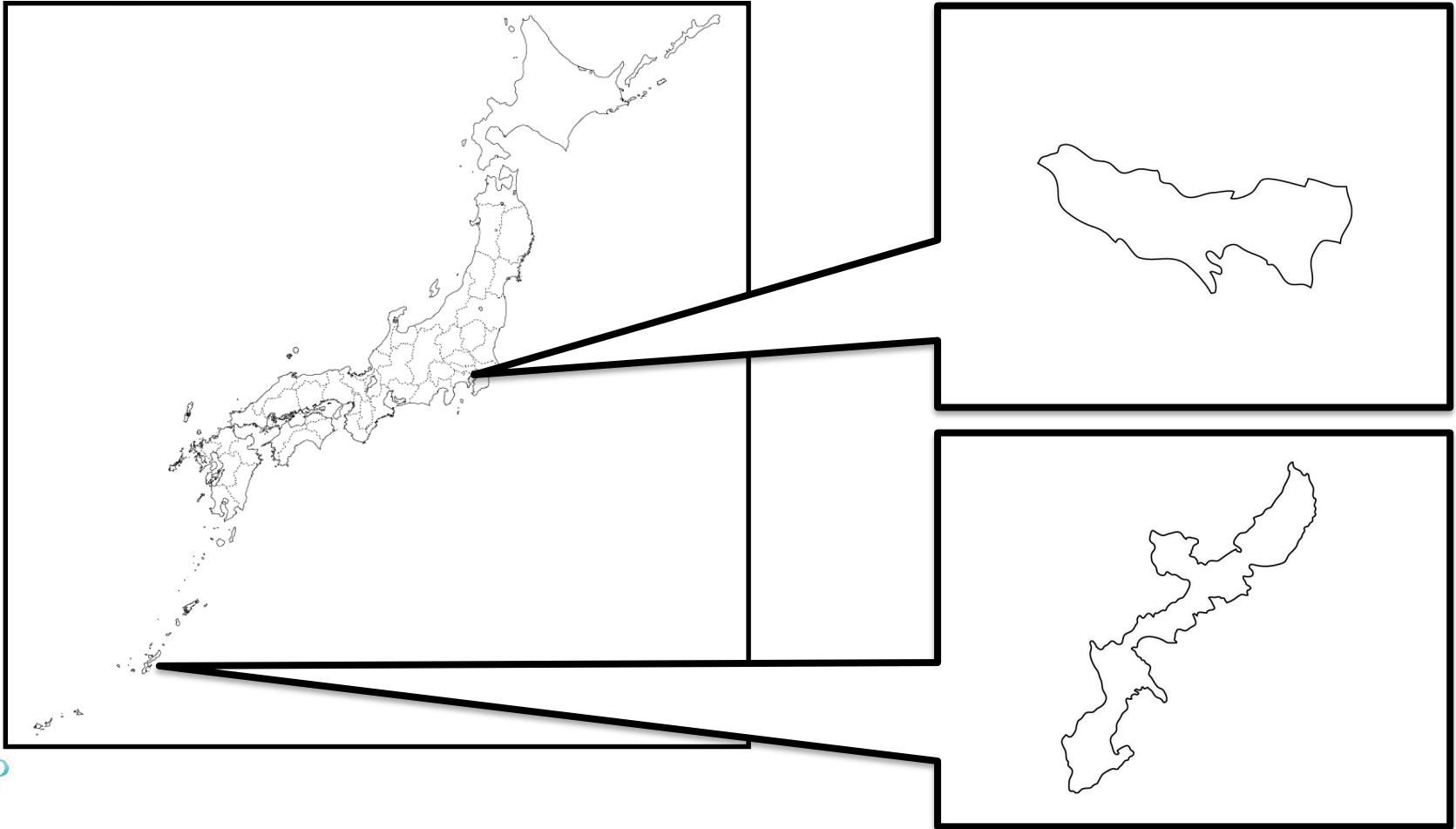
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## **Field operational test**

# Field operational test in Japan



# Field operational test in Tokyo bay area



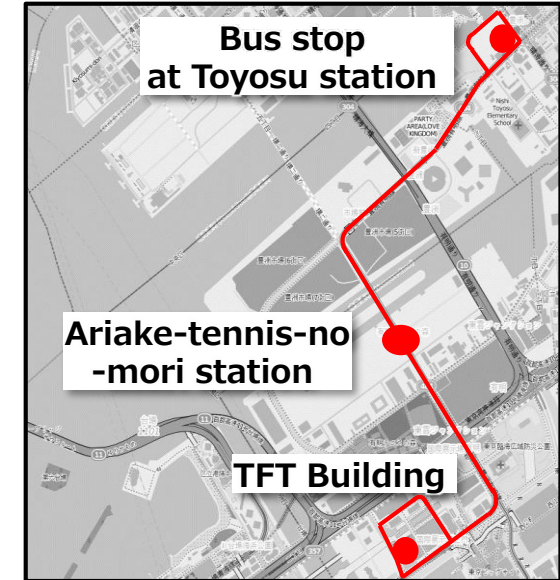


# Field operational test in Tokyo bay area

Field operational test ; 20th November – 21th December  
Demonstration of ART ; 6-7th February

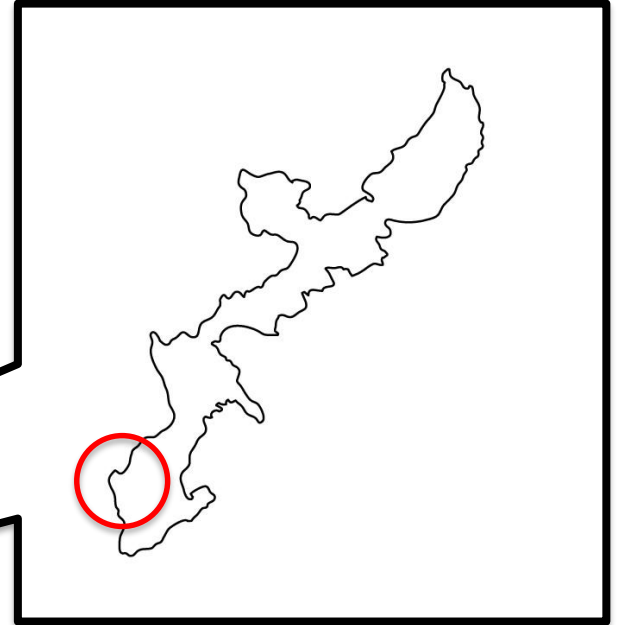
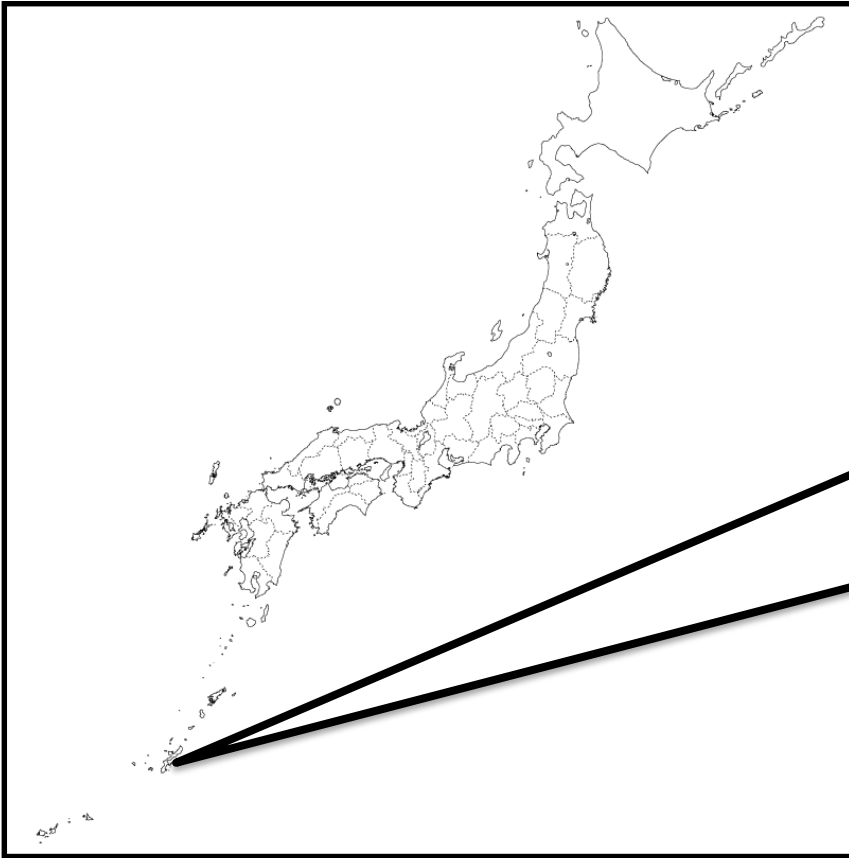


Route map for field operational test  
(Temporary)



★  
We are here.

# Field operational test in Okinawa



Tomigusuku and Naha city  
Okinawa-pref

# Field operational test in Okinawa

Schedule (Temporary)

Field operational test ; 13th February – 8th March

Pre-test ; 31th October- 15th November

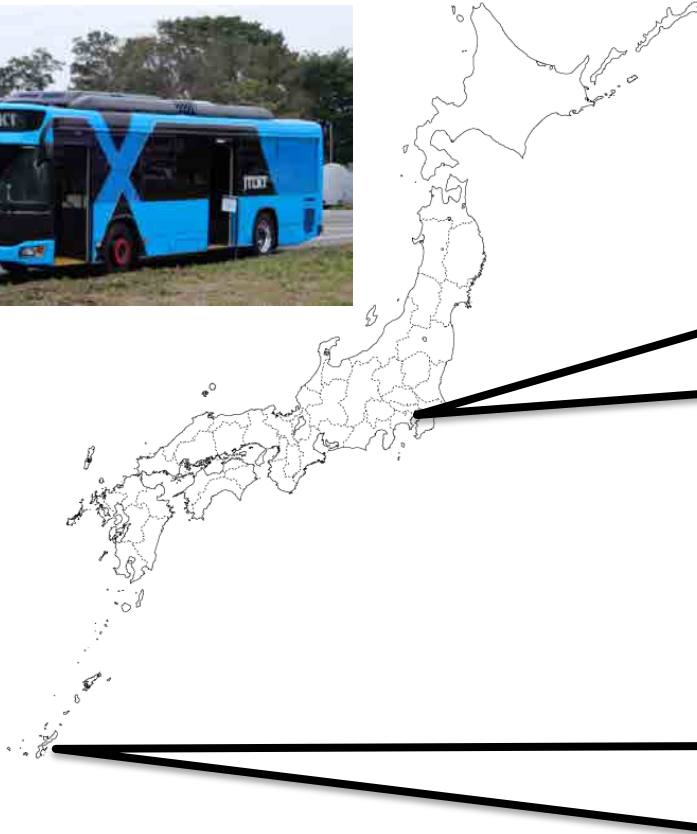
6th January – 24th January



Route map for field operational test  
(Temporary)



# Field operational test in Japan



**Thank you**

