Technology Introduction of Low-Speed Automated Driving Mobility-Based Service System

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要旨

　ヤマハ発動機（以下、当社）ではこれまでに、さまざまな自動走行車両を開発してきた。例えば、電磁誘導線による低速自動走行車両 [1] や、測量などで用いられる高精度の RTK-GPS を用いた自動走行車両 [2]、3D-LIDAR と 3 次元地図によるオフロード自動走行車両 [3] などである。

　現在、これらの技術を応用し、複数の低速自動走行車両をオンデマンドで配車が可能な「移動サービスシステム」を開発している。将来的には、高齢者、子連れ、車いす利用者などを含む一般のユーザを対象とした、数キロ四方程度の広さの市街地やリゾートなどでの低速自動走行車両によるサービスの実現を目指している。

　本技術紹介では、上記移動サービスシステムの概要について説明する。具体的には、アスファルトなどの路面の特徴量を用いた自車位置同定によって自動走行する VGL（Virtual Guide Line）を搭載した低速自動走行車両および複数台の低速自動走行車両の交差点調停やオンデマンド配車などを行う管制サーバについて説明する。

1　INTRODUCTION

Over the years, Yamaha Motor Co., Ltd. has developed various automated vehicles. Examples include a low-speed automated vehicle running along an electromagnetic guide line[1], an automated vehicle relying on the high-precision RTK-GPS used in surveying and similar applications[2], and an off-road automated vehicle[3] functioning with a 3D LIDAR and three-dimensional maps[3].

These technologies are currently serving as the building blocks for the development of a mobility service system that allows on-demand dispatching of multiple low-speed automated vehicles. Looking ahead, the goal is to make a low-speed automated vehicle-based service, covering resorts or a few square kilometers in the city center, available to the elderly, people traveling with children, people in wheelchairs, and other average users.

This paper presents an overview of the above mobility service system. More specifically, the Virtual Guide Line (VGL) system that performs automated driving based on localizing the vehicle using the feature values of asphalt and other road surfaces, as well as the control server that performs intersection arbitration and ondemand dispatch of multiple low-speed automated vehicles, are described.

2　OVERVIEW OF THE MOBILITY SERVICE SYSTEM

This section outlines the mobility service system, which consists of multiple low-speed automated vehicles and the centralized control server that controls them (Figure 1).

The mobility service is available from a vehicle dispatching application for smartphones. The application sends a request for a vehicle to the control server, which replies with a notification of the dispatch time and dispatches the vehicle. Users can enter the desired destination in their smartphone or in the on-board tablet to have the automated vehicle take them there (Figure 2).
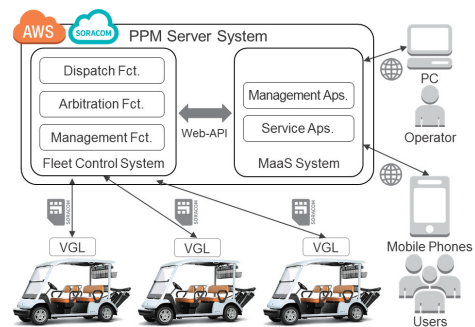

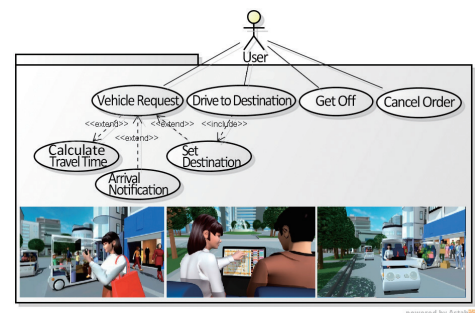Figure1. Overall configuration of the mobility service system

Figure 2. Use cases for the mobility service system

3 VGL-EQUIPPED AUTOMATED VEHICLE

The mobility service system is made up of multiple automated vehicles. In automated driving control, information on the position of the vehicle is crucial. As stated above, technologies to localize the vehicle using electromagnetic guide lines, high-precision real time kinematics (RTK)-GPS used in surveying and similar applications, and a 3D LIDAR using a laser to enable three-dimensional surveying of the surroundings, have been developed.

The technology presented in this paper is the Virtual Guide Line (VGL) automated driving system[4], which was jointly developed with the Southwest Research Institute (SwRI) and uses the feature values of asphalt and other road surfaces to localize of the vehicle. The vehicle is depicted in Figure 3.

In terms of functionality, the VGL system localizes the vehicle by comparing road surface images taken with a camera installed in its lower portion (Figure 4) with data in a pre-recorded map database (image matching) to acquire information on the position and orientation of the vehicle. The path following function that relies on the route to the destination requested via the navigation system and information on its current position to follow that route at a maximum speed of 20 km/h is complemented with an obstacle recognition function that uses the 3D LIDAR to slow down or stop the vehicle if an obstacle is found along the route.

3-1. VGL LOCALIZATION PRINCIPLES

This section provides more details on the localization function that is a distinguishing feature of the above VGL system.

Figure 5 shows the block diagram of the VGL system.

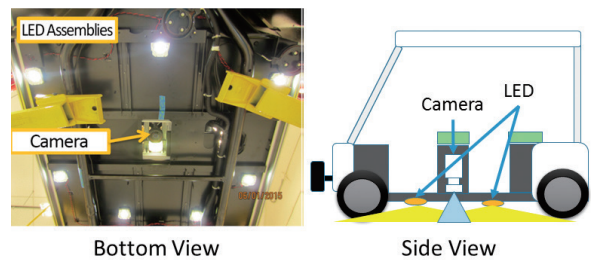**Figure 3. Low-speed automated vehicle equipped with the VGL system**

Figure 4. VGL camera and LED lamps in the lower portion of the vehicle

This function is composed of a camera mounted in the base of the vehicle, multiple LED lamps for the stable taking of road surface images, a controller, and a DPGS-IMU comprised of a differential GPS (DPGS) that is not as precise as, but less expensive than, RTK-GPS and posture
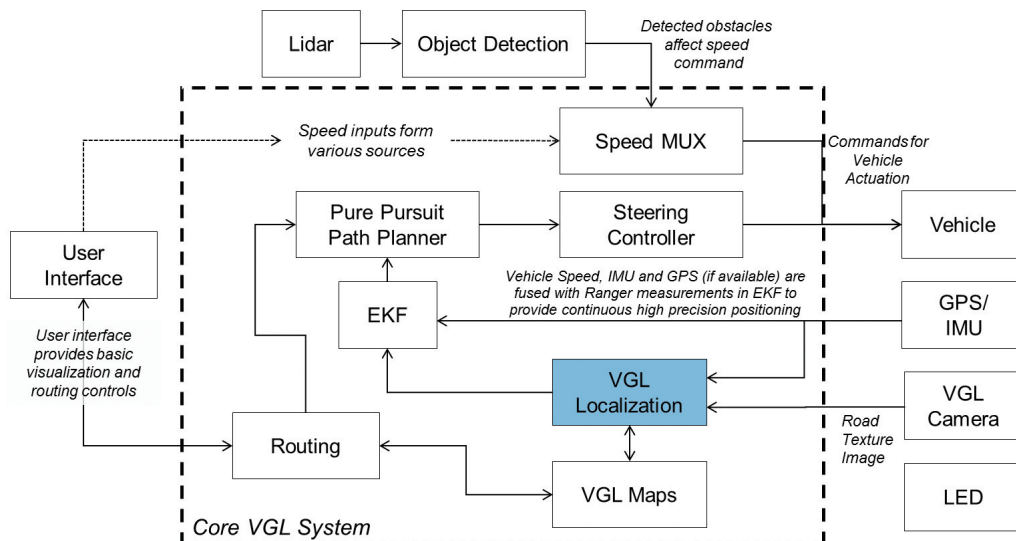

Figure 5. Block diagram of the VGL system

sensors. It also contains a map database with records corresponding to the road surface images and position data. Creating this map database in advance is necessary to perform automated driving with the VGL system. Figure 6 shows the procedure for creating the map, which requires an operator to manually drive a VGL-equipped vehicle while recording road images, DGPS-IMU, and odometry-based vehicle speed data. This makes it possible to extract position information corresponding to the various road surface textures from the map database. In addition, image matching technology is used to join the continuously recorded road surface images without inconsistencies in the overlapping areas, and compensation is applied to minimize errors in the corresponding position and orientation information (Figure 6(b)).

During autonomous driving, features of the road surface texture are extracted from road surface images taken by the camera as shown in Figure 7(a), and image matching is performed against the image data in the aforementioned map database as Figure 7(b). These processes lead to the acquisition of the corresponding position and orientation information illustrated in Figure 7(c). As shown in Figure 7(a), the DGPS-IMU position and orientation information is complemented through an extended Kalman filter (EKF) to improve its robustness, enabling a VGL vehicle to acquire the position and orientation necessary for automated driving even if it becomes temporarily unable to read the road surface texture.

Relying on this VGL localization makes it possible to acquire vehicle position information with an accuracy equal to or better than that of high precision RTK GPS localization technology.
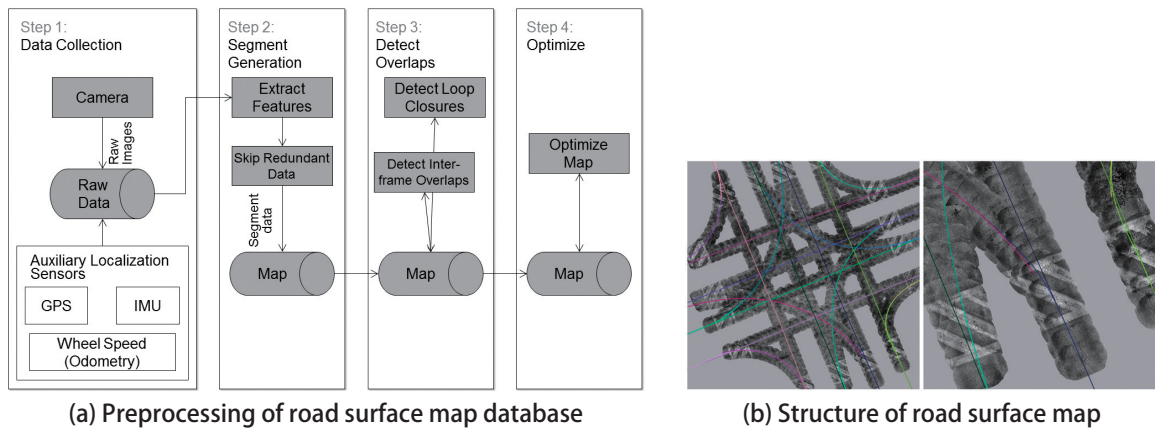

(a) Preprocessing of road surface map database

(b) Structure of road surface map

Figure 6. Road surface map creation for the VGL system (map preprocessing)

(a) Localization processing

(b) Results of road surface texture matching
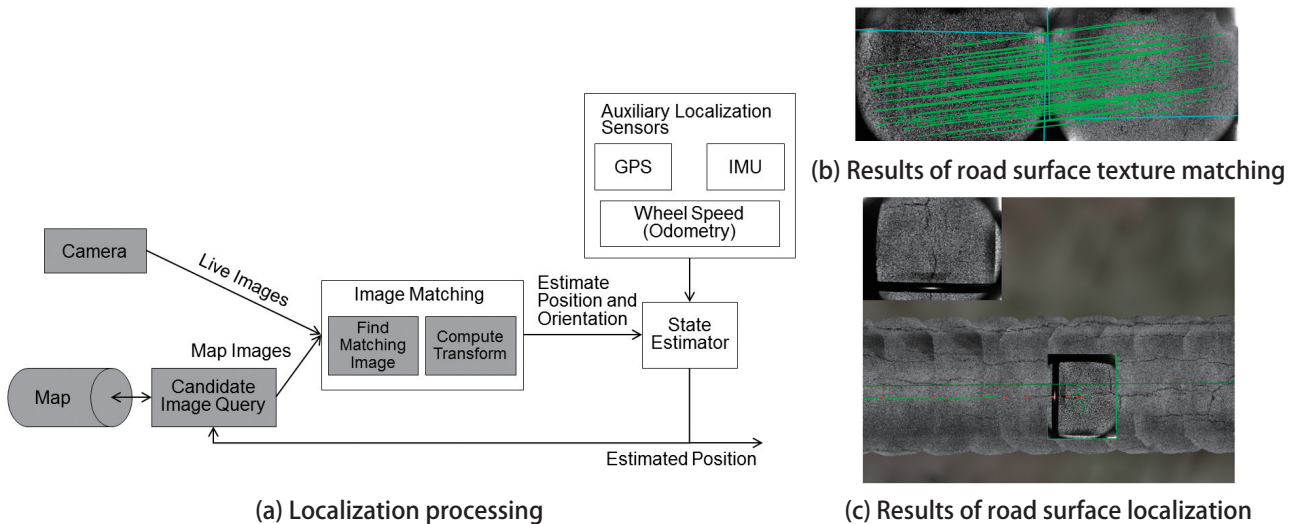
(c) Results of road surface localization

Figure 7. VGL system localization principles
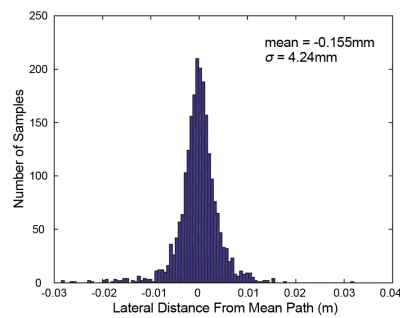
3-2. EVALUATION OF VGL LOCALIZATION PERFORMANCE

The histograms in Figure 8 show the variation in the position recognition accuracy of VGL localization when driving over asphalt or concrete.

As seen in Figure 8(a), positioning accuracy is achieved with an error 2.68 mm on asphalt, and as seen in Figure 8(b), even on concrete, which has relatively little unevenness or other features compared to asphalt, positioning accuracy with an error of 4.24 mm was achieved.

Compared to the error range of 20 mm to 200 mm of the RTK GPS typically used in automated driving systems, the VGL was confirmed to have extremely high localization accuracy.
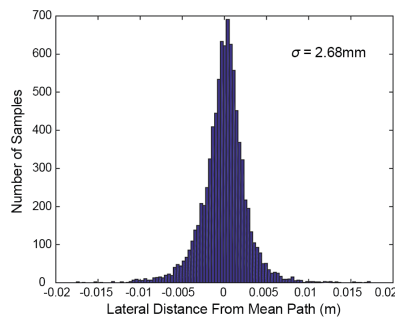
(a) Histogram of localization information on asphalt

(b) Histogram of localization information on concrete

Figure 8. Accuracy of VGL localization (asphalt, concrete)

4 CONTROL SERVER

The control server performs centralized control of the operation of multiple automated vehicles and provides an automated driving-based mobility service. In more specific terms, it offers on-demand dispatching of automated vehicles via smartphone, as well as a merging arbitration function that performs smooth management of the operation of the automated vehicles at intersections. Other features include the implementation of dispatching time notifications for users and operation management functions for operators.

Delivering the basic functions (the database that records vehicle information or supplementary functions such as arbitration) of the control server as a platform enables developers to focus their efforts on developing mobility service applications.

4-1. CONTROL SERVER PLATFORM

The above-mentioned control server platform is described in the following paragraphs.

The server implements arbitration at intersections by sending an authorization to pass through the intersection command to a running automated vehicle. Achieving this type of arbitration function requires a server platform that fulfills various performance requirements, such as real time operation, high load tolerance, and security.

Therefore, the design of a logical architecture capable of meeting the above performance requirements was based on lambda architecture[5], which has a proven itself in stock exchanges systems, whose performance requirements include real time operation and reliability in handling high-volume access requests (Figure 9). Lambda architecture is suited to the parallel processing of multiple data sets with different characteristics, such as data requiring handling in real time or high volume data, and the architecture distinguishes itself by applying the optimal processing technology for each type of data.
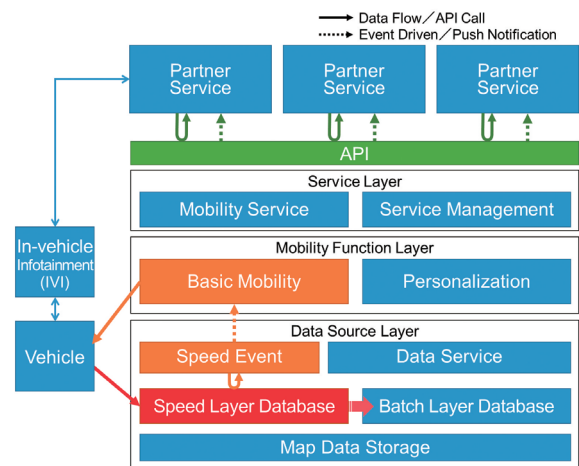

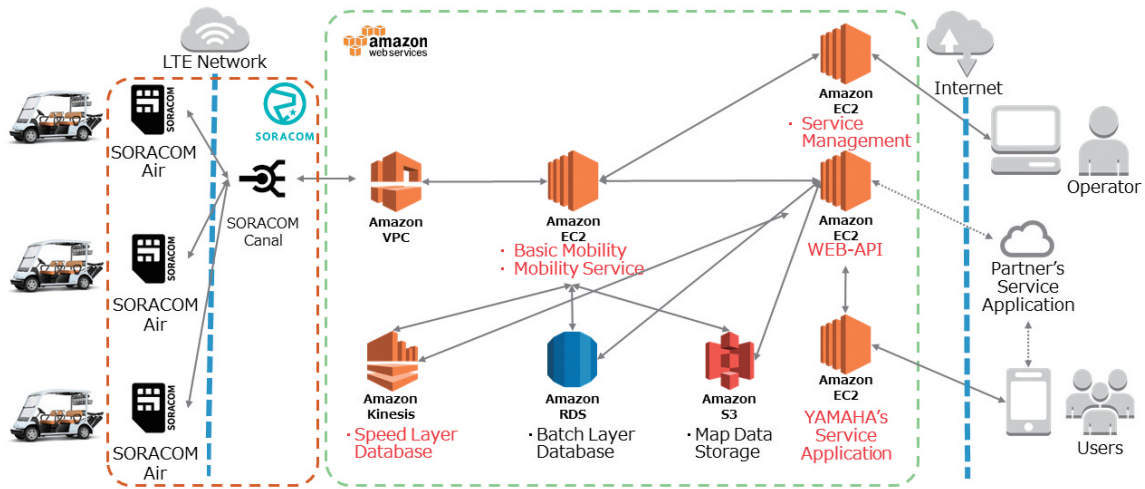Figure 9. Logical architecture of the control server platform

Figure 10. Implementation of the control server platform

To satisfy the above requirements, the resulting logical architecture analyzes the characteristics of the data transmitted between the automated vehicles and the server, and achieves high speed arbitration for multiple automated vehicles by processing data with real time requirements with the Speed Layer Database and Speed Event functions.

The next step, as shown in Figure 10, was to implement the above architecture on the AWS[TM][6] cloud-based platform as a service (PaaS). The Speed Layer Database and Speed Event are implemented through Amazon Kinesis[TM] and EC2[TM]. Adopting this implementation achieved the real time operation required for automated driving. To prevent the hacking of the automated vehicles, vehicle–server communications use the SORACOM[7] service, which provides a connection through a high-security virtual private cloud (VPC) as the transmission route between the LTE network and the AWS server.

Providing a platform for server application development has allowed developers to focus on the development of applications such as the arbitration function. In addition, leveraging the existing large-scale system capabilities of the AWS and SORACOM cloud-based PaaS made it possible to build a stable server platform in a short time. The use of cloud services is also expected to address the issue of server scalability, which will become a necessity when the number of vehicle increases.

4-2. MOBILITY SERVICE SYSTEM AND MOBILITY APPLICATIONS VIA WEB APIS

The platform also features web application programming interfaces (web APIs) for service application development to encourage open innovation-based mobility services that make use of low-speed automated vehicles. Although external access is normally prohibited by security protocols, the APIs are made available to partners who intend to create mobility services.

Figure 11. Examples of mobility service system and mobility applications via web APIs

Using the web APIs enables those partners to perform user authentication or send commands such as vehicle dispatch requests, as well as obtain vehicle use counts, use conditions, or other information in the context of the mobility service system. Simply put, combining these APIs facilitates the development of mobility service systems and mobility service applications that use low-speed automated vehicles.

Figure 11 presents examples of mobility service systems and service applications developed using the web APIs. It can use the user authentication function and retrieve data such as detailed usage by users, information on users, or vehicle operation.

5 CONCLUSION

This paper introduced the Low-Speed Automated Driving-Based Mobility Service System.

More specifically, the VGL system that localizes the vehicle using road surface images and performs automated driving, as well as the control server system that provides mobility services through multiple autonomous vehicles, were described.

Development to reduce costs and further enhance safety, reliability and security is currently being carried out with an eye toward commercializing the mobility service system. There are also plans to make the system more convenient for users by refining the usability of the service applications.

One issue that will eventually need to be addressed is coordination with other ordinary vehicles that cannot be managed with this system. Compliance with dynamic maps using high-precision three-dimensional maps[8] which have promising applications for automated driving on public roads, will be kept in mind in studying ways to address that issue.

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