Autonomous Off-road Vehicles Enable Automation and Labor-savings of Human and Material Transportation

As an effort to solve social issues, such as a decreasing labor force due to an aging society and natural disasters, we are developing autonomous vehicles with the aim of achieving automation and reducing labor.

We have demonstrated element technologies that allow such vehicles to drive autonomously, not only on paved roads, but also on uneven surfaces in mountains and other areas. Also, we have developed a unique optimal autonomous driving logic that takes into account road surface roughness, turning radius and other such conditions and verified its advantages with actual vehicles.

Introduction

In order to cope with the decreasing labor force due to an aging society and natural disasters, autonomous vehicles are needed with the aim of realizing automation and reducing labor.

1 Background

Although autonomous vehicles have been researched and developed targeting paved roads, automation and labor-saving may come to be in demand in the near future to transport people and goods on unpaved roads and uneven surfaces in mountains and other areas.

We are selling the multipurpose off-road vehicle MULE series, which are mainly used on large farms and factories in North America for travel and transportation. They are popular because of the excellent running performance that makes it possible for the vehicles to travel on unpaved roads and mountains, and also the strength of the vehicles themselves. Currently, the movement of people is restricted due to natural disasters and the pandemics, and efforts to realize autonomous operations have been accelerated mainly in the distribution sector.

2 Autonomous off-road vehicles

Despite the impact of the COVID-19 disaster, the multipurpose off-road vehicle market has been expanding and various manufacturers have been introducing new features, bringing about intense competition in the market. In addition, there are new demands for automation and labor-saving of operations to be performed using multipurpose off-road vehicles like the MULE from the viewpoint of cost reduction.

Therefore, we determined to develop autonomous vehicles with the simplest system configuration possible that can automate simple operations and transportation and that can reduce the labor required for such tasks. Specifically, using MULE PRO-FX [1)] as the base, we started developing an autonomous driving technology specific to driving on unpaved roads while drawing on the excellent running performance, strength, and load capacity of the MULE PRO-FX.

3 Development policy

(1) Product concept

Market research on MULE users has revealed that, as shown in **Fig. 1**, they are used for wide variety of applications mainly on farms and ranches, the main use being repetitive routine work such as material transportation and patrols.

Based on this finding, we added a new autonomous driving function to the mass-produced model to allow users to select autonomous driving, remote control, and

(a) For farms and ranches

(b) Transportation of workers

(c) For leisure

(d) For hunting

Fig. 1 Overview of market research (MULE users)

manual control depending on the situation. We will allow customers to experience the autonomous driving function based on the mass-produced model and will improve the vehicle with the feedback received from them.

We also aim to provide vehicle platforms specific to unattended operation through communications with users while retaining the excellent running performance, strength, and load capacity of the MULE.

(2) Use cases

For labor saving and automation of routine work carried out at farms and ranches, we came up with use cases based on actual operations. Examples of use cases are shown in **Fig. 2**. A user uses a tablet or other device to enter the driving route and the vehicle automatically travels at low speed along the specified route, or a user records the route by manually driving the vehicle at the start of

(a) Driving along the route specified using a tablet

(b) Driving based on changes in the road surface environment

(c) Detection and avoidance of obstacles

Fig. 2 Examples of use cases

work and the route is used as the specified driving route.

Because the MULE is used on unpaved roads, the vehicle speed needs to be controlled based on changes in the road surface and obstacles need to be detected and avoided in autonomous driving as well.

4 Technical tasks

This section shows technical tasks to be achieved to allow vehicles to travel safely on unpaved roads along specified routes.

(1) Autonomous driving under rough road conditions

In an autonomous driving system of a vehicle that travels on a general paved road, as shown in **Fig. 3**, based on the output from a camera, radar, and LiDAR sensor, the system recognizes the track conditions including the road structure and traffic participants, such as pedestrians and vehicles. The system also uses a self-localization function to recognize the position of the vehicle itself on the map using the Global Navigation Satellite System (GNSS), map data, and camera. The risk forecasting function uses the recognized information to forecast the behavior of the traffic participants in the future, their intentions, and possible risks. Based on the information that these higher-level functions have recognized or forecasted, the behavior planning function determines the driving path and speed so as to realize safe and smooth driving. Then the vehicle control function determines the driving force (power train), braking force (brake), and steering input (steering).

On the other hand, when driving in an off-road environment, environment recognition sensors, such as LiDAR and camera, may not work properly due to mud spattering on them or vibration during driving. Therefore, a vehicle control method that does not rely on environment recognition sensors is required, which is also necessary in order to have a redundant autonomous driving system.

(2) Route tracking for an actual vehicle

In the assumed use cases, the roads are uneven and the road surface environments also change successively. The load conditions of vehicles also vary. There is a risk of the loaded goods falling or the vehicle toppling during autonomous driving. Accordingly, under the aforementioned road conditions, whether a vehicle can travel with the conventional GNSS-based route tracking function needs to be examined in driving simulation and driving tests using an actual vehicle.

5 Development of elemental technologies

For the task of autonomous driving under rough road conditions described in "Technical tasks," we constructed logic to estimate rough road conditions based on vehicle behavior. Speed planning logic that does not rely on environment recognition sensors and that enables safe and efficient driving on rough roads was constructed as follows.

- Estimate the roughness of the road surface of the route based on the vehicle behavior during the first drive.
- Determine the speed limit based on the roughness of the road surface and turning radius.
- Maximize the acceleration and deceleration within the friction circle of the tire force.

(1) Estimation of the roughness of road surfaces

In order to estimate the roughness of a road surface from vehicle behavior during driving, measurement items that are strongly correlated with the roughness of a road surface, such as acceleration of the vehicle body, vehicle speed, and suspension stroke, need to be used.

We decided to use vehicle speed and acceleration of the vehicle body for estimation as they are easy to measure. In actual service conditions, the loading conditions change each trip and such changes affect the

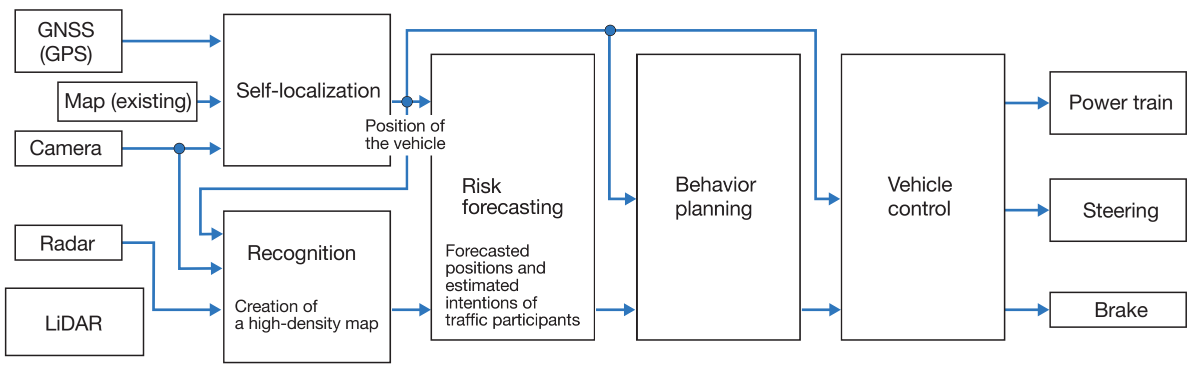


Fig. 3 Concept of autonomous driving system

acceleration of the vehicle body. Therefore, the influence from varied live loads also needs to be considered.

In order to examine whether the roughness of a road surface can be estimated when the vehicle speed, acceleration, and loading conditions are known, we used the three road surfaces each with a different roughness shown in **Fig. 4** to simulate driving at a supposed vehicle speed. As a general method to understand the degree of projections and depressions on a road surface and frequency components, power spectral density (PSD) is used. Therefore, the roughness of each road surface was organized with PSD. **Figure 5** shows the relationship between the vehicle speed and the acceleration of the vehicle body for each road surface obtained in the simulation. When the vehicle speed, spring vertical acceleration RMS, and loading conditions are known, the roughness of the road surface can be estimated.

(2) Vehicle speed control considering the roughness of road surfaces and turning radii

Based on the information on the roughness of road surfaces acquired in the aforementioned examination and set route information, we determined a speed limit that served as an indicator of vehicle speed control under rough road conditions. We assumed that the speed limit was inversely proportional to the roughness of a road surface, and so the estimated value when a vehicle traveled at 10 km/h was used for calculation as a typical value of the roughness of road surfaces. In addition, when a vehicle goes around a curve with a small radius of curvature, lateral acceleration is generated to prevent the loaded goods from falling. The speed limit was determined such that the lateral acceleration would not go above a preset value.

(3) Acceleration and deceleration considering the friction circle of tire force

Due to the characteristics of tires, a tire can produce force only within the friction circle. That is to say, when a vehicle is traveling on a rough road and thereby the friction circle itself is small or a transverse force is generated during turning, the longitudinal force that can be generated

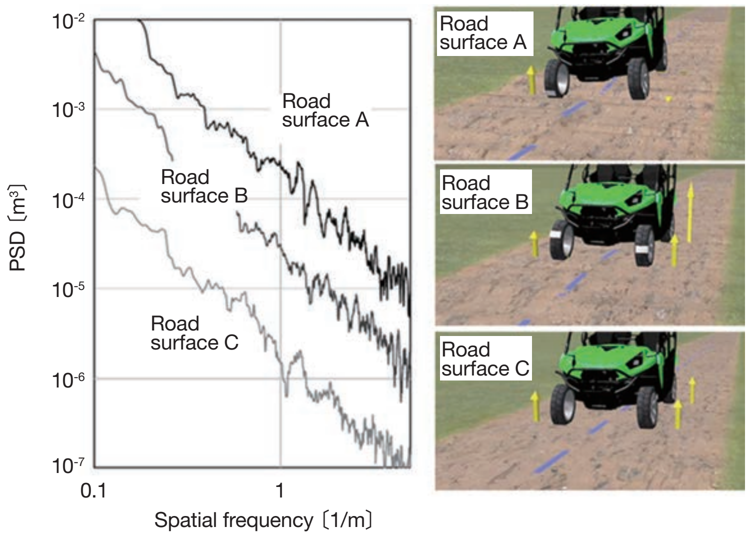
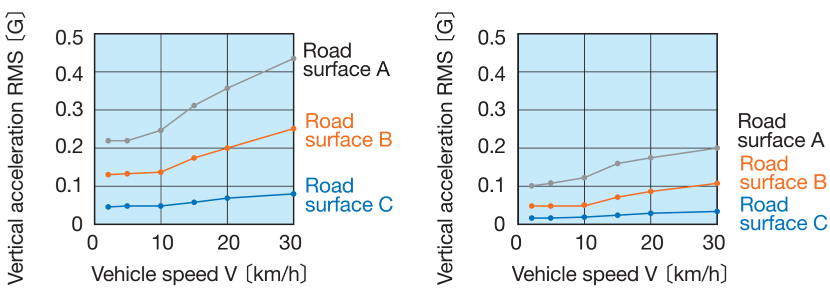


Fig. 4 Roughness of the road surfaces used for simulation



(a) Empty

(b) Loading condition of 1 ton

Fig. 5 Relationship between vehicle speed and vertical acceleration

is smaller. We considered this fact to determine the speed limit such that the longitudinal acceleration would be less than or equal to the upper limit.

6 Driving tests

To examine the route tracking of an actual-size vehicle as described in "Technical tasks," we modified the MULE PRO-FX (base) to develop a prototype vehicle and used the vehicle to test driving under flat and uneven rough road conditions [2].

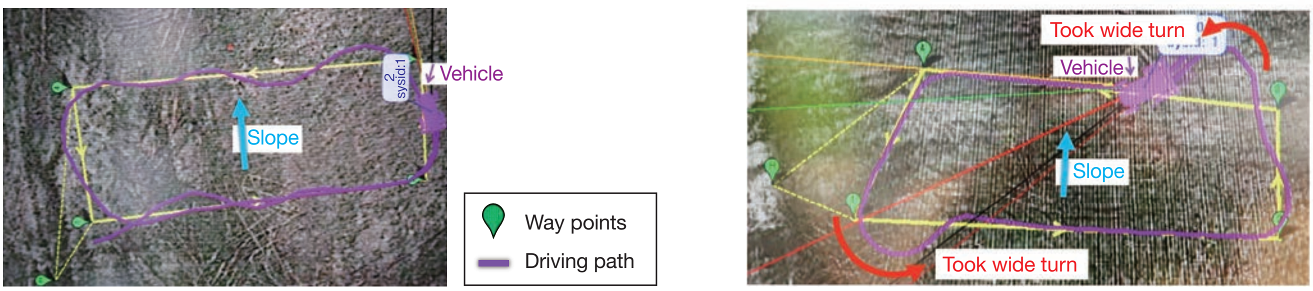
(1) Driving test on a flat road

In order to adjust the autonomous driving parameters for an actual-size vehicle, a driving test was performed on a flat road. As shown in **Fig. 6**, way points were provided and the maximum speed was 10 km/h. The test showed that the vehicle can travel a square track and figure-eight track with good accuracy. In addition, assuming a use case involving remote control, driving by radio control operation was also checked.

(a) Driving situation

(b) Driving route

Fig. 6 Self-driving test on a flat road



(a) Maximum speed 10 km/h

(b) Maximum speed 15 km/h

(c) Slope

Fig. 7 Self-driving test on an uneven surface

(2) Driving test under uneven rough road conditions

The results of the driving test on an uneven road surface are shown below. In the test shown in **Fig. 7**, way points were provided in advance in a figure-eight track and a route tracking driving test using GNSS was performed.

Figure 7 (a) shows the driving path in the square circuit track when the maximum speed was 10 km/h and **Fig. 7 (b)** shows it when the maximum speed was 15 km/h. The test has confirmed that at a maximum speed of 10 km/h, the vehicle can travel with good accuracy. On the other hand, the test with the higher maximum speed shows that the vehicle took a wide turn at corners and thereby the accuracy of the route tracking decreased. As described above, the test revealed a problem with the route tracking during turning due to the influence of the inertia of the vehicle although such a problem was not observed in the test on the flat road. In the future, it is necessary to take measures in terms of hardware such as vehicle control, throttle, and brakes.

Conclusion

As an effort to overcome social issues such as a decreasing labor force and natural disasters we are developing autonomous vehicles with the aim of achieving automation and reducing labor.

The basic technologies have been developed and we will start demonstration experiments as the next stage in cooperation with local governments in Japan. Specifically, autonomous vehicles will be used on farms and forest roads to perform actual operations in demonstration experiments to check the performance and convenience. We will construct an optimum system and aim at putting the new product onto the market promptly through communications with the market including local users.

References

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