

Research on Measurement Method of Road Gradient and Altitude by On-Road Driving

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ABSTRACT

Exhaust emissions from a vehicle under road driving condition is affected by the control state of ECU (Engine Control Unit). This control state highly depends on the driving force of the vehicle. The driving force is nearly equal to the driving resistance, which is the sum of the acceleration resistance, the air resistance, the rolling resistance and the gradient resistance. Although it is essential to take an accurate measurement of the road gradient, it is quite difficult to evaluate the gradient resistance in testing on-road driving.

In this study, the measurement methods of the road gradient and the altitude with GPS, gyro sensor and height sensor are reported. The road gradient under the on-road driving condition is evaluated by the combination of measuring the pitch angle with the gyro sensor and measuring the vehicle gradient with the two height sensors. Verifying of this method, the altitude of the driving test route is also evaluated.

From the measurement values of height sensors, the gradient of vehicle was obtained. Then, the road gradient is obtained by taking account of this vehicle gradient to insure the accuracy of gradients. This method has a high repeatability, and yet is able to solve an inaccuracy problem associated in conventional measurement method of road gradient and altitude.

INTRODUCTION

On the hazardous substances exhausted from vehicles, its total emission has been decreased by tightened exhaust gas control, improved combustion technology of engines, improved quality of catalysts and others. While the total emission has been decreased, it can be said that local contamination by the exhaust gas along roadsides has not been improved yet [1]. Though a fuel economy of a vehicle at least by modal tests has been improved as the fuel economy standard has been introduced, the actual fuel consumption the on-road driving is not clarified for the most part. To ascertain the local pollution conditions and to obtain and analyze the actual fuel economy of a vehicle, it is essential that the exhaust gas from actual on-road driving should be evaluated on a quantitative basis. The behaviors of exhaust gas in the on-road driving are largely affected by control conditions of ECU (Engine Control Unit), which are, in turn, depending on how large force is required for vehicle driving.

The driving force required for a vehicle can be estimated if it is known how large driving resistance the vehicle sustains. The driving resistance sustained by the vehicle consists of four types of resistance: acceleration resistance, air resistance, rolling resistance and gradient resistance (see APPENDIX). The gradient resistance is able to be computed by weight of vehicle and road gradient (Eq. 1) [2].

$$R_e = Wg \sin \theta_r \quad (\text{Eq. 1})$$

where,

g : gravitational acceleration [m/s²]

R_e : gradient resistance [N]

W : weight of vehicle [g]

θ_r : road gradient [deg.]

The road gradient is important not only for the emission and the fuel economy but also for the safety of the vehicle. For example, in the case of a heavy duty trucks, the amount of power that is absorbed by the brake system at the road gradient of 6% cannot be ignored. The information of the road gradient is very helpful for drivers as well as for vehicle manufacturers in terms of the emission, the fuel economy and the safety. The road gradient, which is indispensable to know the gradient resistance, is difficult to ascertain. In fact, this ascertainability is one of the tasks for the general on-board measurement. Prevailing measurement methods of road gradient include the evaluation of atmospheric pressure measurements and evaluation of measurements by acceleration meter. The atmospheric pressure measurement method is considered as unestablished in terms of measurement method [3], because no high-accuracy atmospheric pressure meter is available as to enable delicate changes of altitude to be differentiated. On the other hand, the acceleration meter measurement method evaluates the road gradient by detecting the acceleration in the forwarding direction of vehicle by the use of a three-axis acceleration sensor unit installed on it [4]. In the case of this acceleration sensor unit, there is a problem that vehicle's gradient occurring when it is accelerated cannot be independently measured. In addition, calculating methods of road gradient, such as the calculation by the driving torque and the estimation method using the Kalman Filter have been researched (Here, the Kalman filter has a function to estimate quantity, which varies momentarily as time passes, in receiving the survey data having diffusion errors) [5]~[8]. Also, the altitude measurement can be taken by a triangulation method taking advantage of GPS [9][10]; however, the accuracy assurance cannot be expected in this method.

OBJECTIVE

This study focuses on a road gradient measurement method which is able to solve those problems. In this method, a gyro sensor is installed to measure a pitch angle, in combination with a height sensor installed on the front and rear wheel axles to detect an instantaneous gradient of vehicle due to acceleration or deceleration, thereby evaluating the road gradient. It also focuses on the altitude data of driving route is obtained by referring this gradient to the altitude of datum point. The purpose of this study is to verify

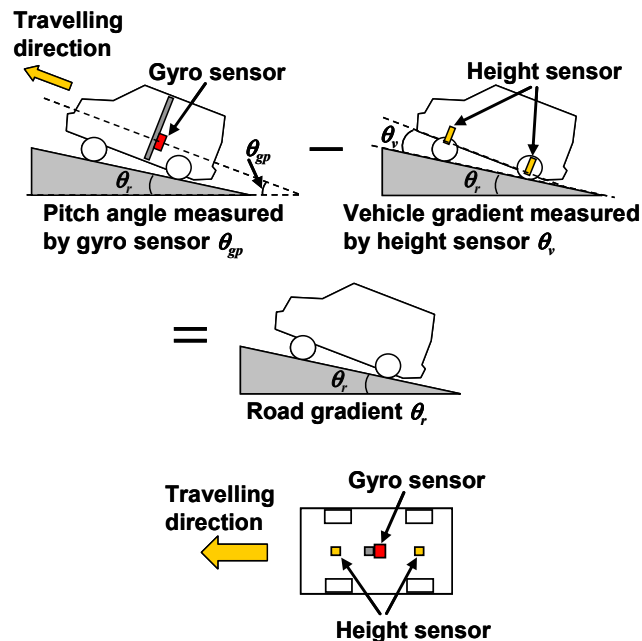


Figure 1 Concept of calculation of road gradient and the sensor arrangement

adequacy and repeatability of the measurement method of road gradient and altitude by making use of data on the driving routes in open road and expressways in Tokyo Metropolis.

EVALUATION AND MEASUREMENT METHOD OF ROAD GRADIENT AND ALTITUDE

COMPUTATION OF ROAD GRADIENT AND ALTITUDE

As referred to in the previous section, a road gradient cannot be computed with high accuracy in the on-road driving test, unless any gradient of vehicle in acceleration or deceleration is taken into account. In this study, a road gradient has been computed with a gyro sensor and a height-sensor installed on the test vehicle. Fig. 1 outlines the test scheme concept and the sensor arrangement.

First, height sensors are fixed around the front wheel axle and the rear wheel axle of vehicle, the distance from the bottom body level of vehicle and road surface, D_f and D_r respectively, were measured both for the front and the rear. A differential between D_f and D_r is divided by the distance from the front sensor to the rear sensor, D_w to obtain an instantaneous gradient of vehicle θ_v (Eq. 2). Next, the vehicle gradient θ_v is deducted from a pitch angle θ_{sp} detected from the gyro sensor installed inside and at the center of the vehicle to obtain a momentarily varying road gradient θ_r (Eq. 3). By combining the road gradient θ_r with a momentarily travel distance X_t , variation

of the instantaneous altitude is able to be obtained; however, this approach will fail to obtain the instantaneous altitude without any reference altitude. Then, by separately providing the altitude at the starting point H_{ref_0} in the test route, the instantaneous altitude value is obtained (Eq. 4).

$$\theta_v = \sin^{-1}((D_f - D_r)/D_w) \quad (\text{Eq. 2})$$

$$\theta_r = \theta_{gp} - \theta_v \quad (\text{Eq. 3})$$

$$H_{cal} = H_{ref_0} + \int_0^{X_i} \sin \theta_r dx \quad (\text{Eq. 4})$$

where,

D_f : distance from the bottom body level of vehicle and road surface near the front wheel axle [m]

D_r : distance from the bottom body level of vehicle and road surface near the rear wheel axle [m]

D_w : distance from the front and rear height sensors [m]

H_{cal} : estimated altitude value [m]

H_{ref_0} : reference altitude value at the starting point [m]

X_i : momentary travel distance [m]

θ_{gp} : pitch angle surveyed by gyro sensor [deg.]

θ_r : gradient of road [deg.]

θ_v : gradient of vehicle [deg.]

For the purpose of comparing the altitude value H_{cal} estimated above, the reference altitude value H_{ref} was taken from the altitude data shown in a numeric map published by Japan Map Center Foundation [11][12]. The same approach was taken for the reference altitude value H_{ref_0} at the starting point in Eq. 4. The measurement system used for this study included surveying of latitude and longitude by using GPS; however, such GPS-measured value was used only when the reference altitude was obtained from the numeric map.

COMPUTATION OF ROAD GRADIENT AND ALTITUDE

As for the measurement method described above, the measurement items are the distance between the bottom body level of vehicle and road surface near the front wheel axle D_f ; distance between the bottom body level of vehicle and road surface near the rear wheel axle D_r ; and, pitch angle θ_{gp} measured by gyro sensor. When using the numeric map, data on the location of vehicle, namely latitude and longitude, is required and hence GPS survey was indispensable.

Used for the measurement of the pitch angle was Oxford Technical Solutions Ltd.'s IMU (Inertial Measurement Unit) RT3100. For the reason that in addition to a high accuracy gyro sensor, this unit includes Kalman filter and GPS antenna, the latitude and longitude is able to

measured at such a location as a tunnel where GPS signal cannot be received in a sound condition. Table 1 shows the major specifications of the IMU. For measuring the distance between the wheel axis and road surface, Corrsys Datron's height sensor HF-250 was used. Table 2 shows the major specifications of the height sensor. In this study, a gasoline passenger vehicle with 2,488 cc engine displacement was used as a test vehicle.

Table 1 Main specifications of gyro sensor with GPS

Model name	Oxford Technical Solutions RT3100
Position measurement method	SPS / DGPS
Position accuracy	SPS: 1.8 m DGPS: 0.4 m
Velocity accuracy	0.1 km/h
Roll angle accuracy	0.05 deg.
Pitch angle accuracy	0.05 deg.
Heading angle accuracy	0.1 deg.
Maximum update rate	100 Hz

Table 2 Main specifications of height sensor

Model name	Corrsys Datron HF-250
Measuring range	100 ~ 350 mm
Resolution	0.1 mm
Linearity	±0.2%
Sampling rate	1 ~ 8 kHz
Light source	Laser
Wave length	660 nm (red)
Approx. spot size	1 mm x 2 mm

MEASUREMENT OF ROAD GRADIENT AND ALTITUDE IN OPEN ROAD AND EXPRESSWAYS

According to the method above, on-road driving test was conducted on the open road and expressways in Tokyo Metropolis to measure the road gradient and altitude.

MEASUREMENT BY OPEN ROAD DRIVING

As an open road route in Tokyo Metropolis, selected was a section from Ikegami, Ota-ku to Mita, Minato-ku of National Highway Route 1, about 9.5 km long. Fig. 2 shows the relevant part of National Highway Route 1. Since this section includes upward slopes of 2% or more and downward slopes of -2% or less in gradient, it is