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Development of Driving Cycle for Hybrid Electric Tactical Wheeled Vehicle

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Abstract

This paper describes development process of a driving cycle for a hybrid electric tactical wheeled vehicle. The process is composed of documentation of a mission profile, acquisition of driving simulation data and generation of driving cycle by data processing. The document of a mission profile describes a military operation including vehicle maneuver and operation of mission equipment. A virtual driving simulation environment was built and used to acquire driving simulation data. Driving simulation was carried out 5 to 10 times in order to increase the reliability of data. The most suitable data was selected and the final driving cycle was generated after data processing. The driving cycle developed in this research is used to improve the fuel economy of a hybrid electric tactical wheeled vehicle.

Keywords: Driving Cycle, Tactical Vehicle, Wheeled Vehicle, Hybrid Electric Vehicle

1 Introduction

Recently, research on the hybrid electric vehicle which had started in the field of passenger cars has been spreading to the area of commercial vehicles and military vehicles. Especially, hybrid electric military vehicles can improve combat capabilities by reducing fuel consumption, supplying high electric power to mission equipment, low noise driving mode without use of an engine, and so on.

One or more driving cycles are required to measure fuel consumption of a vehicle. Various driving cycles, for example, FTP-75, are used for passenger cars and many other driving cycles are developed and used for commercial vehicles such as buses and trucks.

Driving cycles for military vehicles are not released due to security reasons. The US Army TARDEC (Tank Automotive Research, Development and Engineering Center) has been developing new driving cycles for hybrid electric military vehicles in HEVEA (Hybrid Electric Vehicle Experimentation & Assessment) program by real vehicle driving tests[1]. Virtual combat vehicle experimentation for duty cycle measurement was done by Mark Brudnak, et. al. in TARDEC[2].

ADD (Agency for Defence Development) has been developing a hybrid electric tactical wheeled vehicle and its driving cycles. This paper describes development process of the driving cycles.

2 Development of Driving Cycle

2.1 Summary

In this research, the development process of driving cycle is composed of documentation of a mission profile, acquisition of driving data and generation of driving cycle by data processing. A mission profile is a document which describes a military operation including vehicle maneuver and operation of mission equipment. A specific area of Korea was selected to develop the mission profile.

The mission of the virtual Korean future infantry regiment with several tactical wheeled vehicles was described with respect to time. The mission profile has information about vehicle maneuver path, road condition, vehicle target speed, the operation time of mission equipment, etc.

In order to acquire vehicle driving data from the generated mission profile, a virtual driving environment which is composed of a driver simulator, a vehicle model, and a virtual terrain model was built. A real soldier drove the vehicle model in the virtual environment based on the given mission profile and the driving data including the actual maneuver path, the actual speed of the vehicle and the driver's operation data were measured. The whole driving path was divided into several parts on the basis of the position where the vehicle stops and idles for a while. The driving simulation was done 5 to 10 times at each driving part in order to increase the reliability of data.

At last, the most suitable driving data was selected at each driving part and the final driving cycle was generated after data processing and putting it all together.

2.2 Documentation of Mission Profile

Before generating a mission profile of the Korean tactical wheeled vehicle, a representative area for standard terrain data should be selected. The area containing various types of roads including main road, local road and tactical road are required to describe many kinds of operations such as attack, defence and high speed movement. The area should have one or more top of mountain and at least one communication station. The locations of military base camps are also important. According to the criteria, a specific Korean area of 10 km × 30 km near DMZ (demilitarized zone) was selected.

After selection of the representative area, an operation scenario was described based on a virtual Korean future infantry regiment with a commander vehicle and two communication vehicles. The operation time is 72 hours including defence operation, delaying action/withdrawal, reconstitution and offensive operation. A mission profile is then documented as a form of Table 1 which includes the road condition, gradient of road, distance and time of vehicle movement, average velocity of vehicle and operation time of mission equipment.

The vehicle speed is most important factor for generation of driving cycle. In this research, the average velocity of vehicle is verified by the results of Korean army's analysis report. It suggested that the maneuver speed of vehicle is calculated by multiplying the base speed and delaying factors. The delaying factors are factors for mission-oriented protective posture (MOPP), unit posture, environment, terrain condition, form of road, CBR (chemical, biological, and radiological) contamination, road gradient, and day and night condition.

Finally, an abbreviated version of mission profile is generated because the full version is too long to simulate and test the vehicle. The short version is approximately 35 minutes long.

Table 1: The form of mission profile

road condition	gradient (%)	distance (km)	time (h)	average velocity (kph)	operation time of mission equipment (min)
non-paved	0-10	0	0	0	0
	10-20	3.62	2	27.2	3
	…	…	…	…	…
paved	…	…	…	…	…
…	…	…	…	…	…

2.3 Acquisition of Driving Data

Vehicle driving data should be acquired by real vehicle test or vehicle simulation in order to make a driving cycle from a mission profile. It is hard to guarantee repeatability and consistency of driving data by real vehicle test because military vehicles are mainly operated on non-paved roads and hilly mountains. In this research, a virtual driving environment was built and the driving data were acquired by driving simulation that was repeated several times.

Virtual driving environment is composed of a real-time vehicle model, a virtual terrain model and a driver simulator.

Real-time vehicle model consists of a vehicle dynamics model and a powertrain model. The vehicle dynamics model made up with 15 bodies, 14 joints, and 8 cut joints. There are 27 relative coordinates and 16 constraints, so its degree of freedom is 11. Double wishbone type suspension kinematics is included and non-linear spring, damper characteristics are input. Powertrain model is composed of front and rear driving motors, two 2-step reduction gears, two differentials, four brakes, four hub reduction gears, an engine/generator set and a battery as shown in Figure 1. The major specifications of vehicle and powertrain are in Table 2.

Table 2: Specifications of vehicle and powertrain

Specification	Value
GVW	5.3 ton
Length from front axle to CG	2.0 m
Length from rear axle to CG	1.3 m
Generator max. power	110 kW
Front and rear motor power	120 kW
Nominal battery voltage	680 V

Generally, the integration step size of the powertrain model is relatively smaller than that of the vehicle dynamics model. If those two step sizes are equal, total simulation time should be long. In this research, dual rate integration method was applied. The step size of powertrain simulation was set 5~10 times smaller than that of vehicle dynamics simulation. So, the driver's inputs such as acceleration/brake pedal position, steering angle and gear shift can be quickly applied to the model.

A virtual terrain model for a specific Korean area was built in this research. The digital elevation model (DEM) which sequentially stores the altitude data of cross points of equally spaced boxes was used to represent the area. Figure 2 shows an example of DEM representation of terrain.

Driver simulator is composed of two computers (a simulation computer and a visualization computer), two monitors, speakers and driver interface as shown in Figure 3. The real-time vehicle model is operated in the simulation computer. The visualization computer receives driver's inputs such as acceleration/brake pedal position, steering angle and gear shift from the simulation computer and sends the vehicle data including position and velocity to it via 1 Gbps LAN.

Driving simulation using the virtual driving environment was performed to acquire driving data. We separated the driving scenario into parts with the points where the vehicle stops and idles. A real soldier drove the virtual vehicle 5 to 10 times at each part in order to increase the reliability of data. We call the separated parts as microtrips[3].

2.4 Generation of Driving Cycle

In order to generate driving cycle, the best followed driving data were selected at each microtrip. The best followed data could be selected using the RMS (root-mean-square) of the difference between the target speed and the simulation speed.

The selected simulation data is fluctuating due to the gradient and roughness of road. We used a filter of equation (1) for smoothing the velocity and gradient data.

$$v_{smoothed}(t) = \frac{1}{h}\sum_{s=-h}^{h} k\left(\frac{s}{h}\right)\cdot v(t+s) \qquad (1)$$

The function $k(x)$ in equation (1) weights the measured speed just before and after the time t and its formulation is in equation (2). In this research, h=4 sec has been used[4].

$$k(x) = \begin{cases} \frac{h^2-1}{h^2}(1-x^2)^2 & (x^2<1) \\ 0 & otherwise \end{cases} \qquad (2)$$

After smoothing, those filtered data was concatenated with each other. The idling part of zero speed and gradient was inserted into the joint point to represent the vehicle stop motion.

The final driving cycle is shown in Figure 4.

3 Comparison to other cycles

The driving cycle developed in this research is compared to other cycles as shown in Table 3. The major characteristic of the developed cycle is that it includes road gradient. The average upward and downward gradient is 8.12 % and -5.36 %, respectively. The maximum upward and downward gradient is 35.6 % and -25.2 %, respectively. The average acceleration and deceleration is 0.23 m/s^2, -0.21 m/s^2, respectively. The average and maximum velocity is 26.9 kph and 57.9 kph, respectively. The driving distance and time is 15.9 km and 2124 sec.

The velocity and gradient distributions are shown in Figure 5 and 6, respectively. The most frequent velocity at which the tactical vehicle should run is 10 kph ~ 20 kph. About 80 % of driving cycle's gradient is less than 10 %.

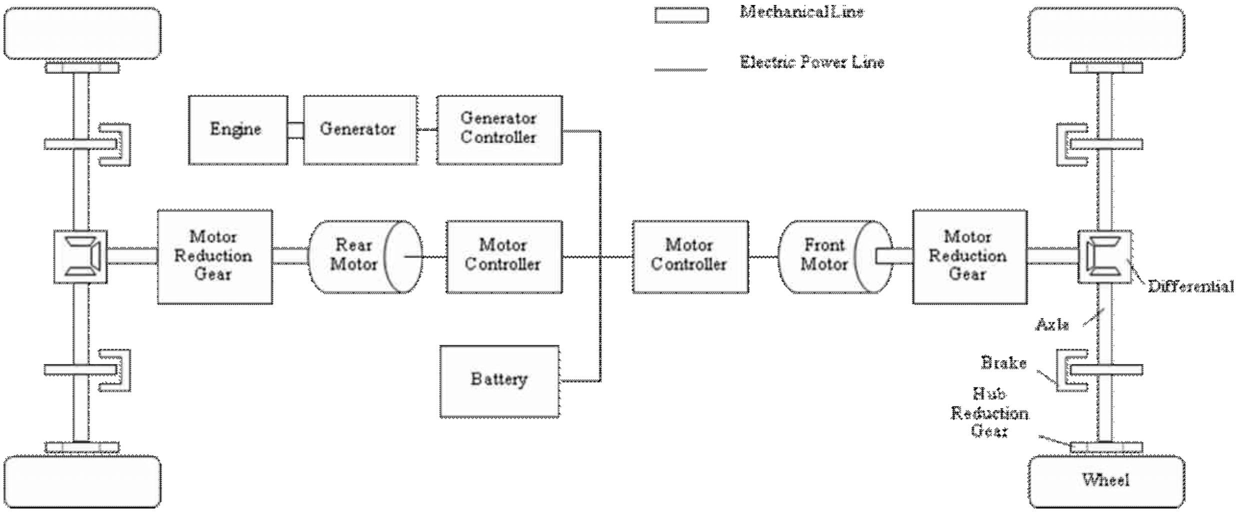

Figure 1: Powertrain model of hybrid electric tactical wheeled vehicle

Table 3: Comparison of driving cycle

	Avg Grad + (%)	Avg Grad- (%)	Max Grad + (%)	Max Grad- (%)	Avg Decal (m/s^2)	Avg Accel (m/s^2)	Max Decal (m/s^2)	Max Accel (m/s^2)	Avg Vel (kph)	Max Vel (kph)	Dist (km)	Time (sec)
developed cycle	8.12	-5.36	35.6	-25.2	-0.21	0.23	-1.67	1.80	26.9	57.9	15.9	2124
FTP-72	0	0	0	0	-0.57	0.50	-1.48	1.48	31.5	91.3	12.0	1369
ECE	0	0	0	0	-0.75	0.63	-0.83	1.06	18.4	50	1.0	195
ECE+EUDC	0	0	0	0	-0.79	0.54	-1.39	1.06	32.2	120	10.9	1220

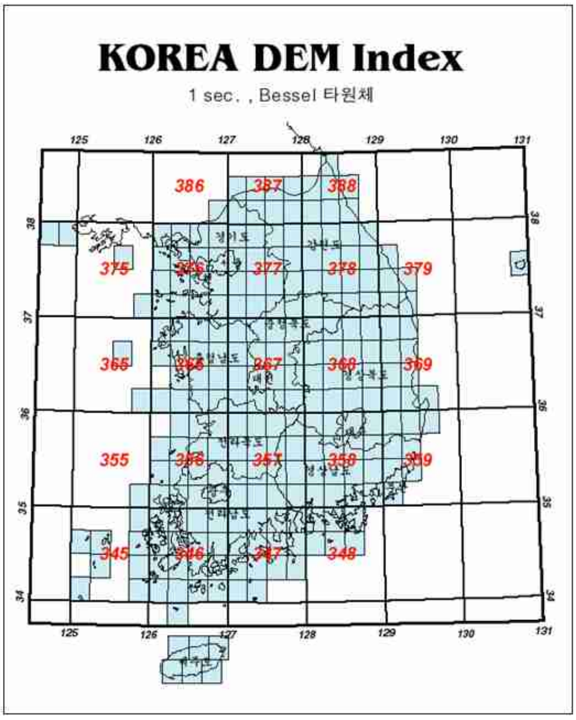

Figure 2: Korea DEM Index

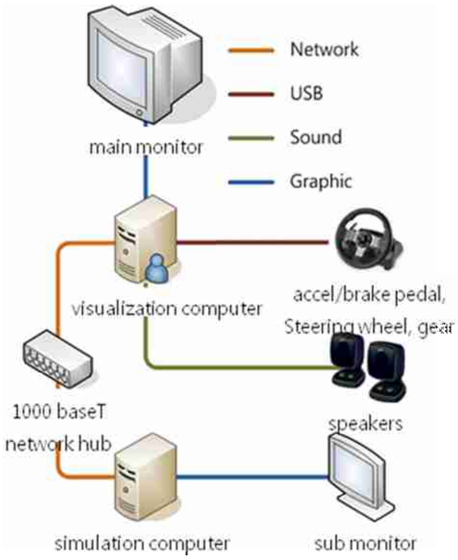

Figure 3: Configuration of driver simulator

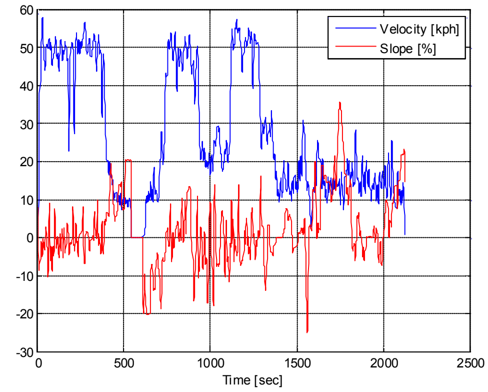

Figure 4: Driving cycle for Korean tactical wheeled vehicle

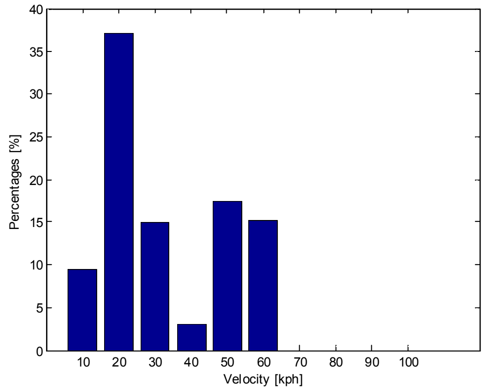

Figure 5: Velocity distribution of developed driving cycle

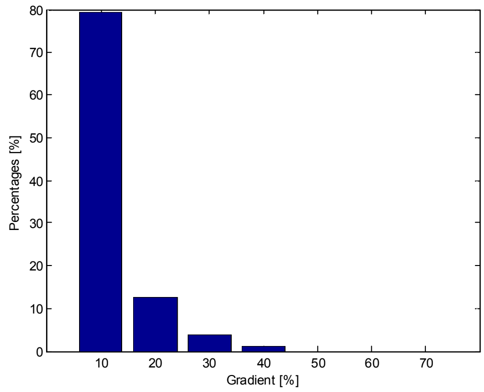

Figure 6: Gradient distribution of developed driving cycle

4 Conclusion

In this research, a driving cycle for measuring fuel consumption of the Korean tactical wheeled vehicle was developed. A representative area was selected and a mission profile was documented considering Korean terrain characteristic and virtual future wartime operation. A virtual driving environment composed of a vehicle model, a terrain model and a driver simulator was built and used to acquire driving data according to the mission profile. Driving data was separated into microtrips and driving simulation was performed several times at each microtrips. Driving data was processed and a driving cycle was generated.
We could measure fuel economy of the Korean tactical wheeled vehicle using the driving cycle.

Acknowledgments

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