Control Strategies for Personal Rapid Transit System

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ABSTRACT

This paper presents a control system design for personal rapid transit (PRT) system and a configuration of an apparatus to assess its control scheme. The control system can be divided into two parts: one is for the vehicle management system that is related with the supervision of the vehicle operation and the other is for the vehicle operational control scheme that is placed in the lower position of the control hierarchy. In this paper we focus on the vehicle operational control scheme that is one of the important features of PRT to guarantee the PRT system performance. In this paper the operational control scheme that can be implemented by using the commercial process boards is proposed and a simple vehicle control algorithm for test is uploaded to it. The calculation results of the process boards are compared with the simulation results that are provided by a simulation platform that combines Matlab/Simulink and Labview Simulation Interface Toolkit.

Keywords: personal rapid transit, vehicle management, vehicle operational control.

1 INTRODUCTION

One of the key features that a new transportation system should realize is to present a solution for the congestion and is to make contribution for the improvement in air quality. The congestion problem and the air quality problem is to be solved by increase the ridership and by choose a proper propulsion system that does not pollute the air, respectively. To maximize the redership the intermediate stops should be eliminated so that the average trip speed can be maximized. It is possible to eliminate the intermediate stops if all stops bypass tracks off the main line. Also if nonstop trip is possible by use of off-line stations ridership can be maximized by place these stations in closely spaced in a network of interconnected guideways so as to eliminate the need for passengers to transfer from line to line. Such features require safe, reliable, rapid switching, realized by use of a new in-vehicle switch having no moving track parts like the conventional rail tracks, operational control algorithm, appropriate switching logic, electronic communication and pollution-free vehicles [1].

In this paper we focus on the design of the operational control scheme providing the avoidance of the impact between the vehicles when they are operated in some speed, with 1-5 passengers per vehicle and with very short headways. The control algorithm for PRT is different from the conventional train control method such as ATS(Automatic Train Stop), ATC(Automatic Train Control), ATP(Automatic Train Protection), ATO(Automatic Train Operation. The conventional control systems for trains are based on the track circuit to detect the train position, but PRT control scheme should realize a safe vehicle control in conditions that the guideways are interconnected in a network configuration without track circuit to detect the vehicle position and that vehicles are operated in non-stop from origin to destination. These require a novel control strategy for PRT system.

The vehicle control module is basically made of three elements: the state information of the vehicles in front and in rear, vehicle dynamics, and the speed profiles or brake curves to control the vehicle speed . The speed profile is produced by the central control computer or by the vehicle on-board computer based on the state information of the vehicles in front and in rear [4][5][6]. In order to develop the vehicle control algorithm that determines the system performance, it is necessary to use an effective simulator and an evaluation tool to test the designed controller [2][3].

In this paper we propose an apparatus for the development of the vehicle control scheme for PRT, employing VME Bus type PowerPC process module and a monitoring device. For simulations, a system which combines Labview Simulation Interface Toolkit and Matlab/Simulink is used.

First we present the control methodologies of the PRT vehicles and the quadratic equation to produce the brake curve (or speed profile) for the vehicle. Next we show a simulation platform that combines Labview Simulation Interface Toolkit and Matlab/Simulink . Finally we show the configuration of the proposed apparatus and the calculation results for the brake curves of the vehicles which run with simple operational scenarios for testing.

2 VEHICLE CONTROL

Since PRT system does not use rail system to transmit control signal information between wayside facilities and the on-board vehicle computer a specific communication system like wireless communication which is very popular technology during the last ten years may be able to be employed for the control of PRT vehicles, if the reliability of the wireless communication is guaranteed.

When the communication based control technology is applied to PRT system it is possible to select two different kinds of control methods. One is based on the fundamental concept that guarantees a safe distance between the vehicles. In this case a movement authority for each vehicle is in the central control module, which means that the central control module has the parameter information for making brake curves of each vehicle. On the other hand each vehicle just calculates the speed pattern when it receives the parameter values from the central control module. Therefore a lot of control tasks are centralized to the central module and the central module should have capability to handle them. The other is a technology that focuses on the improvement of the operational efficiency in a way that the minimum headway between vehicles is maintained so as to increase the line capacity. In this method each vehicle needs to know the location of the vehicle in front and has to gather the information by itself that is necessary to calculate the vehicle speed pattern in a given section. Therefore the key feature of this control method is that the communication reliability between vehicles should be guaranteed. In this paper the first method is employed.

3 QUADRATIC EQUATIONS

A brake curve of a vehicle in the PRT system can be calculated by using the equation (1).

$$v_B = \sqrt{2a(D_b - d_{Bp} - v_B t_{br}) + v_{cf}^2} \quad (1)$$

Equation (1) means that if there is information of the final speed to be reached v_{cf}, the instantaneous vehicle position d_{Bp}, the block distance or the brick wall safety distance D_b, and the deceleration a, it is easy to calculate the current vehicle speed v_B. In reality the vehicle speed v_B is a function of distance and the speed versus distance indicates the vehicle speed pattern or the vehicle brake curve, corresponding to either the speed code received from the track signaling system or the speed command set by the driver during the operation like in a conventional ATC (Automatic Train Control) system. In eq. (1) t_{br} is the delay time for the brake reaction of the vehicle in rear, which means the delay time to activate the brake system of the vehicle in rear from the moment that the vehicle in front has activated its brake system.

4 OPERATIONAL SCENARIOS

In order to verify whether the proposed configuration of the apparatus is proper or not, it is necessary to design a control algorithm to be tested in the proposed system. The control algorithm for the test is divided into two parts. One is for normal mode shown in Table 1. and the other is for an emergency mode. In normal mode fourteen virtual speed transitions are set for the 3 km guideway. The final speed limits in each step are set arbitrarily. For an emergency mode both vehicles assume that there is no activation of the emergency brake for either vehicle running on the guideway at a constant speed. However, once the vehicle in front activates the emergency brake, the vehicle in rear should activate its emergency brake as soon as it recognizes the activation of the emergency brake of the vehicle in front. Then the vehicle in rear should stop while maintaining the safe distance.

Table 1. Speed transitions in each step for normal mode

Steps	Distance	Initial Speed	Final Speed
1		0 kmh	40 kmh
2	260 m	40 kmh	40 kmh
3	400 m	40 kmh	30 kmh
4	760 m	30 kmh	30 kmh
5	1000 m	30 kmh	60 kmh
6	1500 m	60 kmh	60 kmh
7	1600 m	60 kmh	40 kmh
8	1760 m	40 kmh	40 kmh
9	1900 m	40 kmh	30 kmh
10	2260 m	30 kmh	30 kmh
11	2500 m	30 kmh	60 kmh
12	2700 m	60 kmh	60 kmh
13	2900 m	60 kmh	30 kmh
14	3000 m	30 kmh	0 kmh

5 SIMLATION PLATFORM

A simulation platform that combines Matlab/Simulink and Labview Simulation Interface Toolkit is employed.

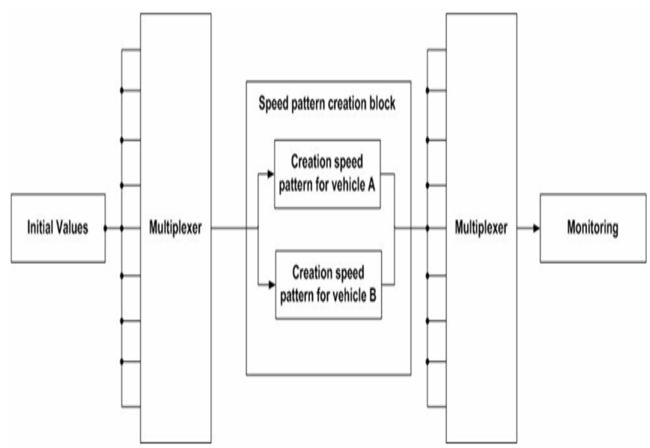

Figure 1: Simulink model

Figure 1 shows the Matlab/Simulink model that provides the brake curves for vehicles in front and rear. Figure 2 is the Labview front panel that displays the vehicle speed and parameter set blocks. Figure 3 and Figure 4 show the simulation results for the normal mode and the emergency mode. Speed patterns of the normal mode for fourteen speed transitions are shown in Figure 3. The dashed line and the solid line present the speed patterns for the vehicle

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in front and in rear, respectively, as they run along a 3 km guideway. As seen in the simulation results, both vehicles follow the operational scenario well, maintaining a distance that has been decided arbitrary. On the contrary Figure 4 indicates the emergency mode that the vehicle in rear (solid line) follows the emergency stop speed pattern when it recognizes the emergency brake activation of the vehicle in front (dashed line).

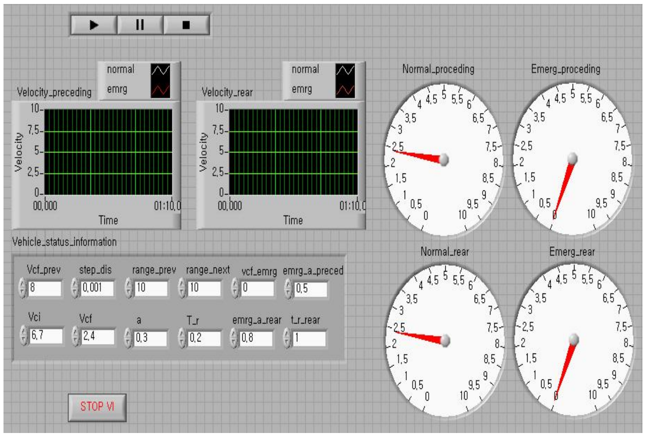

Figure 2: Labview front panel

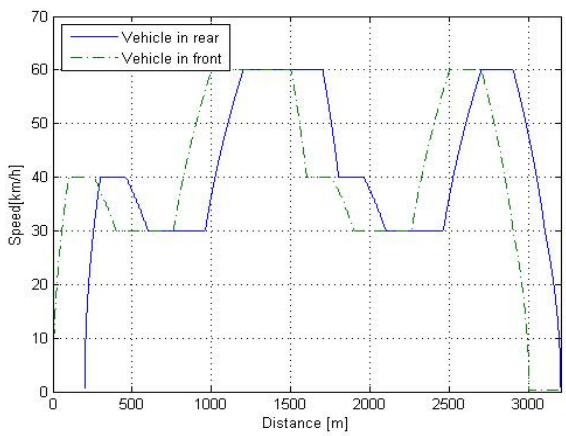

Figure 3: Simulations for the normal mode

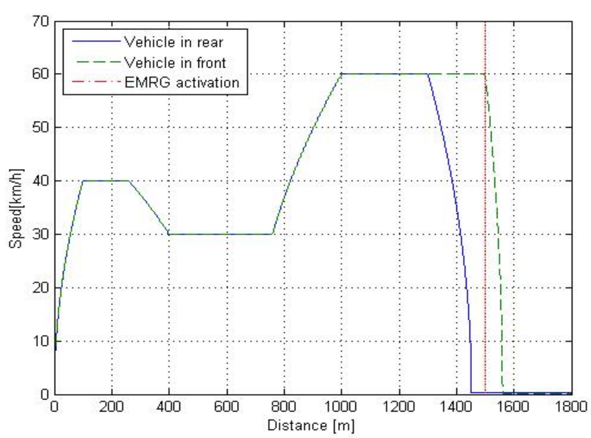

Figure 4: Simulations for the emergency mode

6 APPARATUS CONFIGURATIONS

Figure 5 shows the apparatus configuration that is utilized for the assessment of the vehicle operational control algorithm.

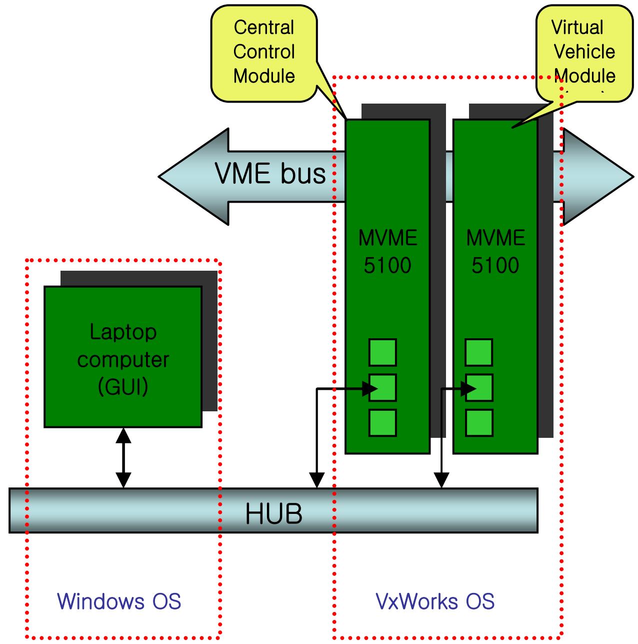

Figure 5: Hardware configuration

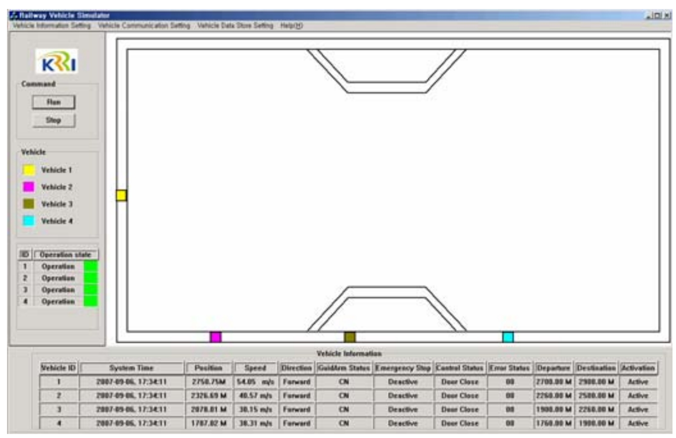

Figure 6: Graphical User Interface

The central control module collects the information from the virtual vehicle module that includes the vehicle operational status and speed for the four different virtual vehicles. It sends the parameter information to each vehicle for the calculation of the speed pattern in the virtual vehicle module. We employ a MPC7410 microprocessor-based VME bus processor module of Motorola Inc., including RS-232 ports, Ethernet ports and VMEVMI2563 I/O board as the central control module and virtual vehicle module. The Ethernet ports are used to transfer the vehicle status and the control information between the central control module and the virtual vehicle module by way of the TCP/IP (Transmission Control Protocol/Internet protocol) communication protocol. Figure 6 indicates the GUI (Graphic User Interface) employed on the 1.7GHz Pentium processor. Four vehicles run on a 3 km guideway based on the predetermined operational scenario, with the vehicle status and the control information transferred between the central control module, virtual vehicle module and GUI & monitoring device. In the lower side of the figure there are information boxes indicating the vehicle status and the control information for each vehicle. The information for the vehicle operational status is shown in the left-hand side of the figure.

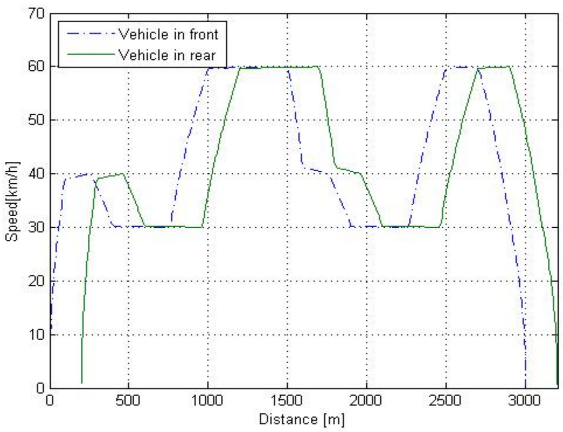

Figure 7: Calculation results for the normal mode

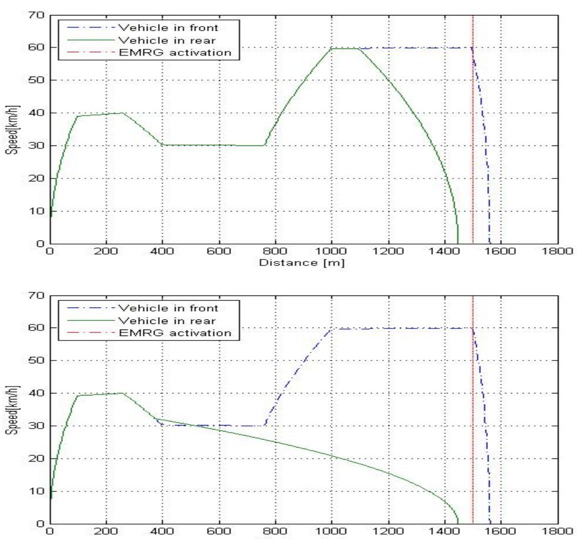

Figure 8: Calculation results for the emergency mode

The calculation results of the MPC7410 microprocessor for the normal mode and for the emergency mode are shown in Figure 7 and Figure 8 In Figure 7, fourteen speed transitions are presented, which are very similar to the simulation results. This means that it is possible for the proposed apparatus to be put to practical use for the evaluation of the designed vehicle control algorithm. Figure 8 shows the calculation results for avoiding the impact between vehicles when the vehicle in front activates the emergency brake. In both figures of Figure 8 the vehicle in front activates the emergency brake 1500 m from the origin and will be stopped. On the contrary the vehicles in rear recognize the activation of the emergency brake of the vehicle in front with some delay but no matter where they recognize the activation of the emergency brake of the vehicle in front they follow the brake curves to be stopped while maintaining the safe distance.

7 CONCLUSIONS

In this paper we have introduced a test algorithm to control a vehicle on a guideway of 3 km in length. The test algorithm is composed of the normal mode that has fourteen speed transitions and the emergency mode to test the impact avoidance algorithm between vehicles. Brake curves for the speed transitions were provided by the virtual vehicle module that receives the vehicle control information from the central control module.

The operational control algorithms for PRT that have been reported up to now were focused on the computer simulation of vehicles, of system operations, and of line management in the overall control hierarchy point of view. However this paper proposes an apparatus which makes it possible to directly evaluate the characteristics of the vehicle operations on the guideway using real hardware. Further, this real hardware can use the same processor and operational control algorithms being designed for a real system.

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