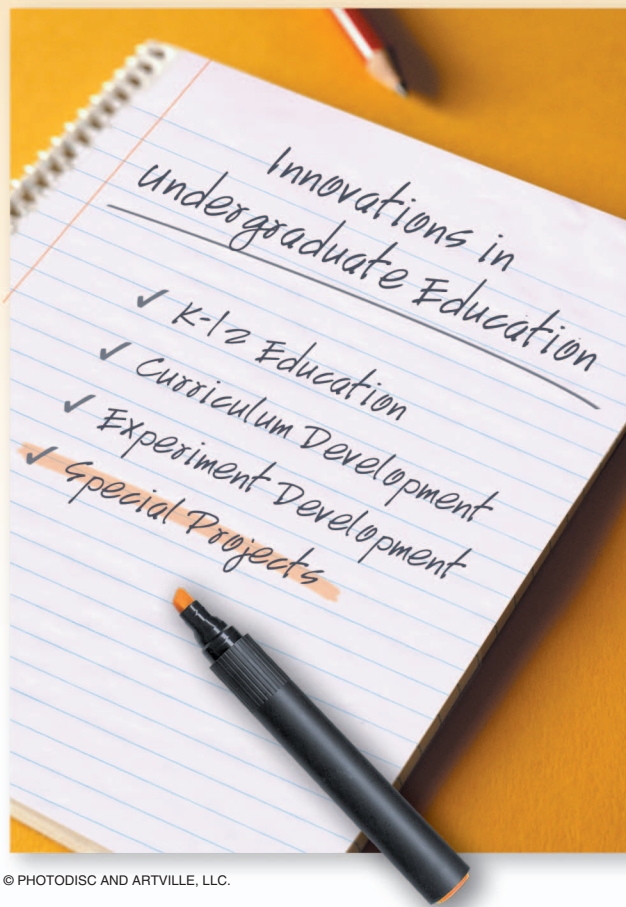


The PeopleMover Educational Project

Design, simulation, and implementation of a “real” control system application



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The PeopleMover project [1], [2] is one of the first examples of project-based education at the Katholieke Universiteit Leuven (K.U.Leuven), Belgium. Senior-level bachelor students in electrical engineering perform this project to enhance their practical skills in subjects that are traditionally taught in purely theoretical courses. The project mimics the electronic and control aspects of a people mover, an autonomous but remotely supervised train that transports passengers between airport terminals. Teams consisting of four students tackle the diverse tasks of speech recognition and acoustic noise reduction for the remote supervisor, wireless transmission by radio link, finite state machine design for main control, sensor integration including infrared, magnetic, and solar cells, power electronics fabrica-

tion, and speed control system implementation. During initial brainstorming sessions, the students specify the layout of the entire system, the tasks facing each team, and the interfacing between different teams. Starting from these specifications, each team designs and simulates an electronic circuit, which is implemented on a printed circuit board (PCB). Finally, all PCBs are integrated into a small-scale model train, shown in Figure 1.

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Our multidisciplinary design project complements traditional education, consisting of theoretical courses and exercise sessions. In such a “real” application, the students encounter practical problems that do not arise in a simulation-only environment. Moreover, students must address multiple design aspects, which require iteration in the design cycle, sometimes even backtracking to the first steps of the design and

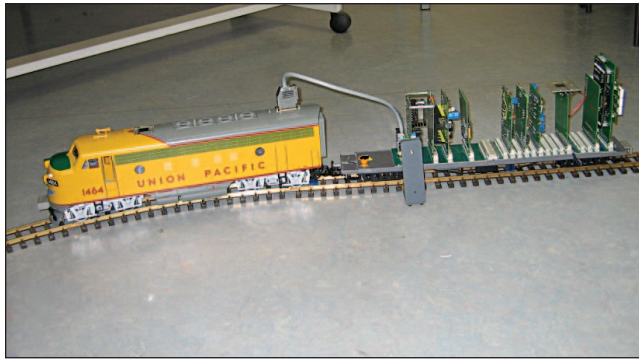


Figure 1. The PeopleMover in its finished form. The PCBs of the different teams are visible, one of which is the speed control system implementation.

redefining the original specifications. In addition, collaboration between different project teams is required, simulating an industrial environment. Finally, the focus on synthesis, rather than analysis, leads to better understanding in advanced courses.

Since students must address multiple design aspects, alternative solutions can arise, resulting in an increased workload for the supervising staff and necessitating the use of nonstandard assessment techniques. In particular, performance assessment is based on presentations of progress and results, team contributions, global outcome, documentation and communication, and continuous evaluation with attention to effort, efficiency, cooperation with other team members, and innovation.

In this article, we discuss the design and implementation of the speed control system. The complete design task is divided into three parts. The *system design* team handles the modeling, design, and simulation of the control system. Simultaneously, the *analog design* team transforms the trans-

fer functions generated by the system design team into an electronic circuit on PCB. The two teams jointly test the circuit, integrate it into the model train, and tune the system.

Modeling, Design, and Simulation of the Control System

The speed control system controls the voltage applied to the train motor so that the speed of the train tracks the desired speed commanded by the finite state machine. Challenges arise when the train encounters disturbances, for example, riding up a slope of 10° . The system requirements specify that three speed levels must be attainable, 0.2 m/s, 0.4 m/s, and 0.8 m/s. Furthermore, for passenger comfort, the acceleration of the train must be in the range $0.5\text{--}1.0\text{ m/s}^2$, without oscillations.

The task of the system design team consists of modeling the complete system, designing the parameters of the control system, and simulating the behavior of the train under various conditions and disturbances.

To model the complete system, the system design team must specify an appropriate control configuration and obtain models for all components involved. Therefore, models of the voltage-controlled train motor, the power driver, and the current and speed measurement units are needed. For didactical purposes, the control system is implemented as an analog proportional integral (PI)-controller-based feedback system [3]–[5]. The students are free to use one PI-controller to control the speed directly by adjusting the voltage (Figure 2) or two PI-controllers in a master-slave configuration. The master PI controls the speed by adjusting the requested current, while the slave controls the current manipulating the motor voltage. The master-slave configuration is known to be safer by avoiding power surges, at the expense of decreased tracking speed and added complexity.

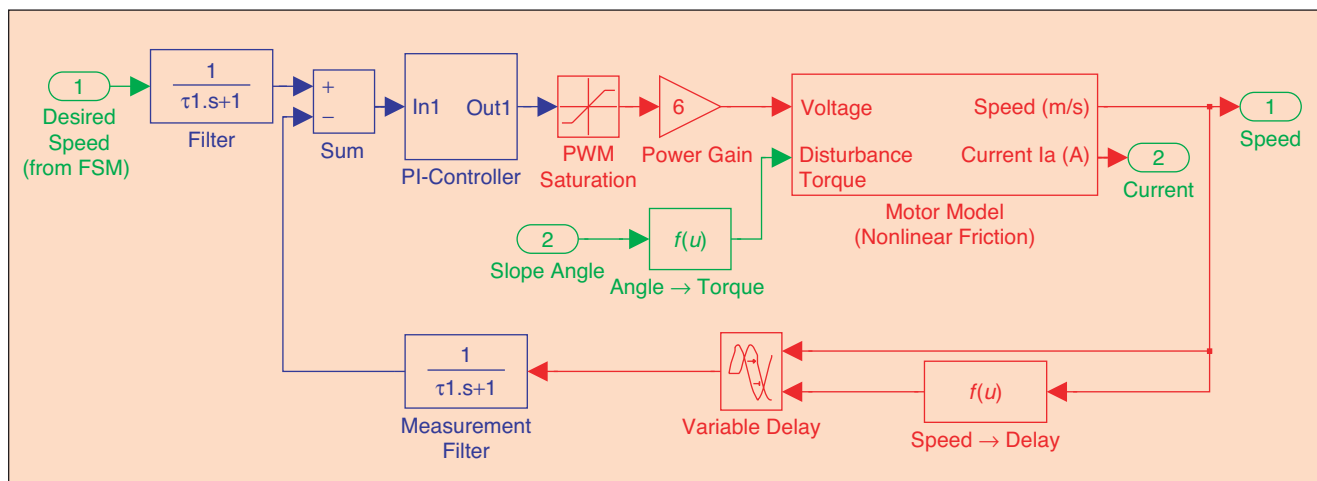


Figure 2. Schematic overview of the complete speed control system in SIMULINK. This feedback control system consists of a nonlinear model of the power driver and the train motor, the speed measurement unit, and the actual control configuration (PI-controller), which needs to be designed. The input signal from the finite state machine is smoothed using a low-pass filter.

With its permanent magnet dc-motor, the train is modeled as a physical system [3]. The unknown parameters of the model can either be measured, for example mass and wheel radius, or identified with a least-squares procedure using steady-state measurements of voltage, current, and speed, such as motor constant, resistance, and friction. In fact, a nonlinear model is identified, since both static and dynamic friction components are modeled by means of a nonlinear friction parameter. The power driver is modeled as a saturation and amplification. The speed of the train is measured using a shaft encoder attached to a wheel, which generates a delay over a fixed distance since the measurement is updated only when a marking on the shaft is detected. Hence, a delay inversely proportional to the speed has to be taken into account in the feedback loop. Furthermore, low-pass filters are used to smooth the reference signal from the finite state machine and reduce measurement noise. The PI-controllers and the low-pass filters are modeled using the transfer functions

$$C(s) = P \left(1 + \frac{1}{T_i s} \right) \quad F(s) = \frac{1}{\tau s + 1}.$$

The design of the control system consists of determining suitable parameters P , T_i for the PI-controllers and τ for the filters, so that all design specifications are satisfied. These specifications are divided into three categories, time-domain specifications such as settling time and overshoot, frequency-domain stability specifications on gain and phase margin, and practical constraints avoiding clipping and windup. Moreover, robustness is taken into account by assuming model inaccuracies such as a change in mass, and by considering a disturbance torque, caused by riding up and down a slope. Since the students are not familiar with control design for nonlinear systems, the complete system is first linearized with friction parameter and delay assumed independent of the speed. The design of this linear control system is performed using MATLAB.

In the second stage, the complete nonlinear system is modeled using SIMULINK; see Figure 2. The influence of the nonlinearities is analyzed, leading to a modification of the control system parameters. The behavior of the train is simulated for different conditions and disturbances. For example, Figure 3 depicts the simulation of the speed and the current when the train accelerates from 0 m/s to 0.8 m/s at 0.5 m/s^2 and also shows the effect of a disturbance torque caused by riding up a slope of 10° .

Design and Implementation of the Electronic Analog Control Circuitry

The analog design team implements the control system. Whereas most undergraduate courses focus on analyzing electronic circuits, in this project the students must confront a real synthesis problem. Therefore, some basic principles of analog circuit design are taught. The students apply this knowledge to transform the system description

Students must address multiple design aspects, sometimes even backtracking to the first steps of the design and redefining the original specifications.

generated by the system design team into an analog circuit implementation. The system description consists of a schematic overview, defining input and output signals, and includes the transfer functions of all logical blocks (D/A converters, filters, PI-controllers), where certain parameters are still undecided or defined as tunable.

First, these transfer functions are converted into an operational amplifier feedback circuit design. This design is not yet realistic because it might require, for instance, capacitor sizes on the order of farads (F). The theoretical circuit is later refined into a practical circuit design, with realistic dimensions (capacitors of μF to pF). During this design phase, teams modify their initial requirements to meet their needs. To guarantee that these modifications do not lead to conflicting specifications, the analog design team must regularly negotiate with other teams on the interface specifications. The system design team delivers the final values of the parameters for the filters and the PI-controllers, and defines ranges for all tunable parameters.

Once the circuit design is finished, the design serves as the input for the PCB-design program CADSTAR. Some practical PCB design issues are taught to the students. For example, the students learn about decoupling capacitors for all ICs. Next, the design scheme is entered, the components are placed and routed, and the final layout is transferred to a facility that delivers a soldered PCB.

Testing of the PCB, Integration into the Train, and Fine-Tuning of the Parameters

Once the design phase is completed, the two teams jointly test and validate the PCB. Testing is considered on functional and parametric levels. Functional testing in this context means ensuring that the PCB is working correctly. Therefore, students must verify that all components

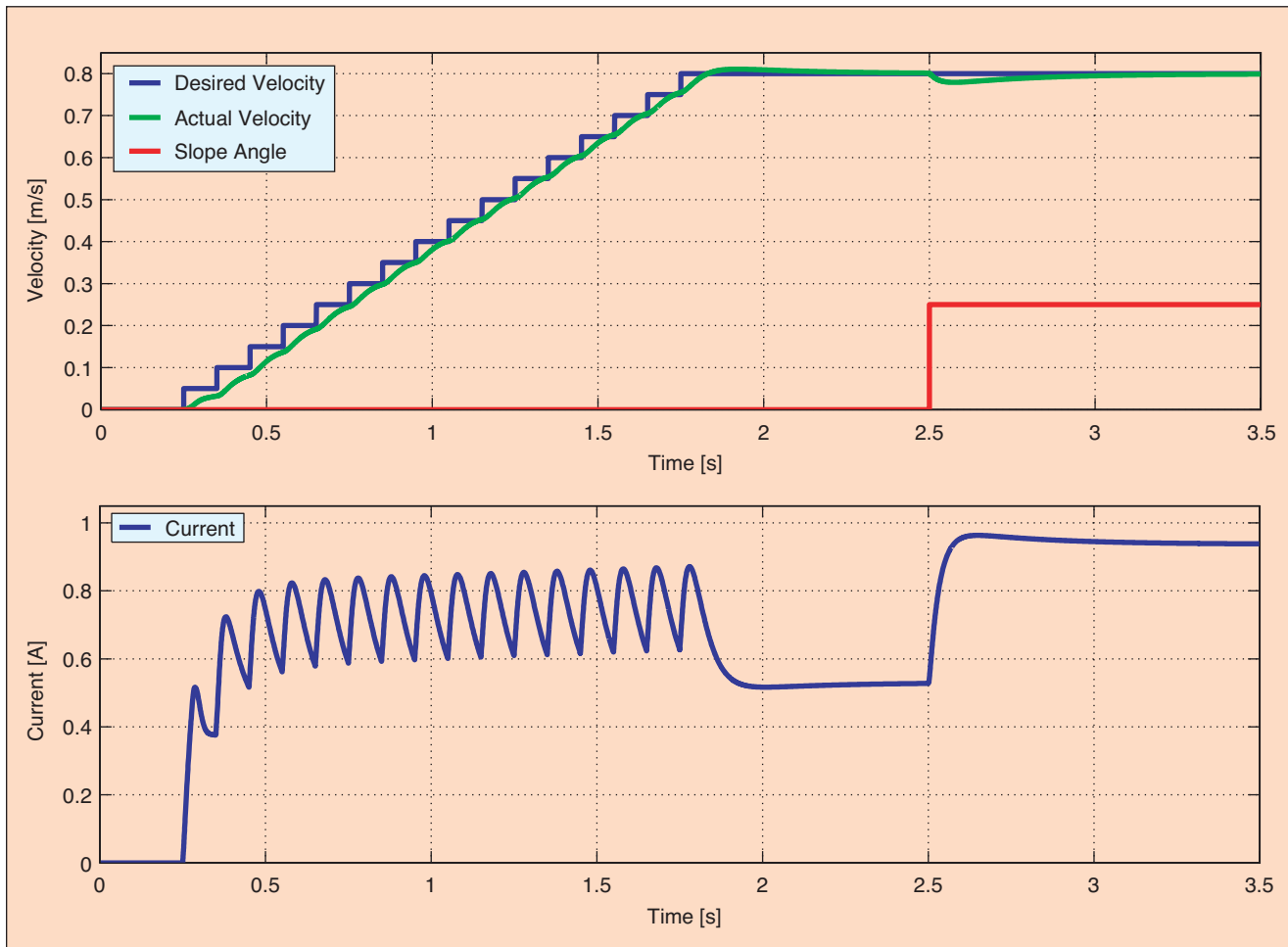


Figure 3. Simulation results for the speed control system. This figure depicts the speed and current as the train accelerates from 0 m/s to 0.8 m/s at 0.5 m/s^2 , and the effect of a disturbance torque, caused by a slope of 10° .

function properly and that there are no incorrect or missing connections in the schematic entry. This aspect of testing is mostly electronic in nature. Parametric testing concerns validating the precise transformation of the system description into the electronic design. This testing involves measuring the cut-off frequency of each filter and comparing the time-domain and the frequency-domain specifications of each PI-controller with the simulations. These tests are formalized in a test plan, which details the requirements of the design, and proposes test procedures that show whether the requirements are fulfilled or not. All of this testing is purely student work, with minimal assistance from supervising staff.

The integration of the speed controller into the miniature train follows the same steps. Validation tests range from detecting whether the correct input signals are transmitted to the controller, to whether the control system can correctly accelerate and maintain the speed of the PeopleMover, even on a slope. Typical problems include misinter-

pretation or ambiguities in the interface documentation, for instance, where active high signals are considered active low by one team, or where most significant bits are interpreted as least significant bits. Also, since the control loop is now closed, differences between model and reality become apparent. Small nonlinearities such as hysteresis in the coupling between the passenger car and locomotive are not modeled but have an impact on the oscillatory behavior of the control system. What at first sight is just a formality (plug the PCB in its slot, and the train will ride correctly), always turns out to be the most hectic, difficult, but rewarding job for the students. It is always extremely satisfying for the students to see the PeopleMover, which has been the topic of conversation and work for many weeks, running smoothly across the room.

Conclusion

The PeopleMover project, and the speed control system task within it, is highly regarded within K.U.Leuven. Stu-

dents and professors alike find this real application a healthy change from courses with purely theoretical lectures and tutorial-like exercise sessions. The goal of having the train run within prescribed specifications, and working toward this goal is a thrilling experience for all of the people involved. The aim of this project is to apply theoretical course material in a practical application, learn how to do multidisciplinary project work, and gain experience with communication between teams. These goals are more than fulfilled. Above all, the students learn in a playful way, with the ultimate reward of seeing the train riding smoothly along its tracks.

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