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Cruise Control of Automobiles

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Abstract: Control of automotive vehicles and engines is a relatively new field in automatic control. Some current applications for engine control are described. Future nonlinear and time-varying automotive systems will require the development of more advanced control schemes. Representative examples for plant modeling, parameter and state estimation, and adaptive control are presented. Therefore, in this thesis the approach of using such additional communicated information from either the second predecessor or the platoon leader is combined with the use of PLC as control method. The goal is to investigate whether any of these two configurations give an increase in performance compared with similar configurations with PLC as control method and compared with a more basic configuration that uses just the direct predecessor's state information with either PLC. Also, the possibly added value of using communicated predicted states, in addition to current states, with PLC is investigated. The CRUISE CONTROL controllers are designed to control the throttle, the brakes, and the gears, subject to operational constraints on acceleration, velocity, and vehicle-to-vehicle distance. The PLC- based CRUISE CONTROL controller contains a proportional feedback of the errors in velocity, position, and acceleration, combined with an automatic transmission scheme, and the control input is restricted at time instants at which a constraint is (almost) violated. The PLC-based CRUISE CONTROL controller at each time step minimizes the expected errors in position and velocity and the corresponding input variation.

Index Terms: Adaptive Cruise Control, Analog Input/ Output, Digital Input/Output, Programmable Logic Controller, Proportional integral, Mixed integer linear

I. INTRODUCTION

Today's advanced automotive systems, such as engines, transmissions, active suspension systems, and brakes, are controlled by microcomputers. Introducing automatic control into these systems, one has to cope with nonlinear plant characteristics, timevarying parameters, and fast dynamics. Some variables essential for the control scheme cannot be measured at all.

Thus, automotive systems are a major new challenge for control engineers. At present, automatic control is used to enhance performance of cars currently in production. Precise control of the air-to-fuel (AIF) ratio is required to efficiently utilize catalytic converters to minimize exhaust emissions. Knock control is came out mainly by using heuristic procedures, taking partial advantage of self-adaptive schemes. Idle speed control has been implemented with conventional proportional- integral-derivatives or with more advanced state-space control, additionally relying on real-time models of the intake manifold.

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1.1) PRESENT CONTROL

The application of electronic control of engines has allowed a substantial reduction in emissions of toxic exhaust gases and improved drivability and specific fuel consumption. This section discusses control of fuel ratio, knock control, and optimal fuel consumption.

1.2) LAMBDA CONTROL

Gasoline engines must get a proper mixture of air and vaporized fuel to bum efficiently. The A/F ratio is called *lambda* (A) and is calculated as follows, where *rizL* is the mass airflow into the engine, ***mK*** the metered fuel mass, and ***LsT*** the A/F mass ratio of stoichiometric mixture.

$$h = (ritL/rn,)/LS$$

Lambda is normalized to be 1 at stoichiometric operation. While the driver regulates the amount of air, *mL*, going into the cylinders, the correct quantity of fuel, *m,*, must be added by the electronic control unit. Due to incomplete fuel evaporation, gas turbo components may be oxidized and reduced by means of a catalytic converter, which is built into the exhaust pipe system. The converter operates, however, only if the A/F ratio lambda controlled precisely to stoichiometry. The average lambda offset must be kept below 0.1 percent. In the case of engine transients, short excursions may be tolerated up to ***3*** percent.

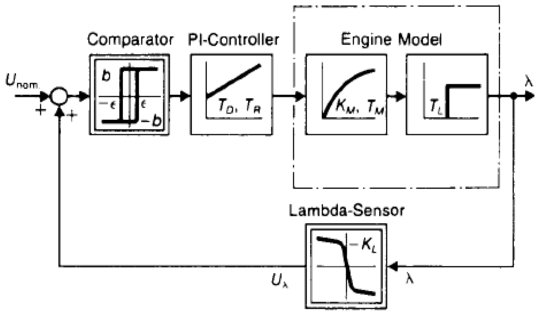

Fig. 1. Block diagram of lambda control [1].

With the help of a so-called lambda sensor, the A/F ratio in the exhaust pipe can be measured. The sensor generates a voltage showing a steep gradient in the area of lambda equal to 1. In this application, the engine may be described by a simplified model, consisting of a delay time *T* and a lag time *T*.

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These times vary with the engines operating condition in the range of delay time *TL* approximately equal to from **100** msec to 1 sec and lag time *T*, approximately equal to from 50 msec to 0.5 sec. The variation is considered in the controller by respectively adapting its parameters. The block diagram of the entire control loop. Due to nonlinearities and delays, a limit cycle of lambda near the nominal value appears. If the size of control parameter *T*, is approximately matched to lag time *T*,, then the frequency of the limit cycle *wx* is determined exclusively by the delay time *TL*. Lance in the combustion chamber, and the limited time available, the burning process is noni deal, even at stoichiometric bons, and, simultaneously, nitrogen oxide are generated in addition to nontoxic carbon dioxide and water vapor.

1.3) ADVANCED CONTROL

Advanced modem control can improve performance and provide more systematic approaches, such as

- Plant modeling
- Parameter and state estimation
- Adaptive and robust control

1.4) PLANT MODELING

It is well known that, prior to controller design; the dynamic behavior of the respective process must be analyzed. This requires derivation of a model that describes process properties to sufficient accuracy. In automotive systems, the modeling job turns out to be far more difficult and time-consuming than the design of the controller itself. Some models currently in use only address static plant behavior; for example, so-called engine maps have been introduced to optimize A/F ratio and ignition angle in each operating point of the engine. The ignition angle is stored for all combinations of engine speed and basic fuel-injection timing. After having determined its present operating point, the ignition controller reads out the optimum ignition angle from the map. Boning and coworkers and Tennant and coworkers developed a computerized procedure to get the optimum values, which is based on the method of Lagrangian multipliers. By this, the engine's fuel consumption is minimized while regarding given constraints for pollutants.

Unfortunately, such static models only partially describe transient behavior of the engine. Currently, only a few useful dynamic models exist. This is due to the problem that models tend to become very complex to match well the physical behavior of the plant; for example, an engine process is comprised of the following disciplines:

- aerodynamics
- thermodynamics
- flanic propagation
- chemical reaction
- mechanics

Automotive engineers have the unpleasant decision of either simplifying models for easy handling, at the risk of unduly reducing their validity. or else leaving models rather complex. being unable to parameterize them for the real world. Plants are usually extremely nonlinear. Time variant, and coupled. Since control synthesis is based primarily on linear. time-invariant theory, models have to be linearized around operating points. By doing this, an additional dependence on **op**erating-point characteristics is introduced. One way to overcome these problems may be to combine partially dynamic models with static control maps. Kielce and Schulz have derived a model, describing the airflow intake manifold of a gasoline engine. For simplification, the intake manifold will be regarded as a concentrated element, where local pressure distribution and pulsations are not considered. Fuel is injected on top of the intake valves of the engine, assuming the gas in the intake manifold to be ideal. The quantity of heat necessary to evaporate fuel will be provided completely by heat conduction from the engine.

State transitions of the gas inside the intake manifold arc then considered as adiabatic. The energy balance describes the alteration of the specific inner energy ***U,*** inherent to the air mass ***rn,*** within the intake manifold volume *V*, due to the specific enthalpies *h,* and *h,* of in- and outflowing air *in,* and *h,* as *Parameter and State Estimation* Assuming the availability **of** a suitable model, it has to be parameterized. If processes are linear and time invariant, an obvious approach would be to determine parameters in an off-line configuration [19]; for example, an engine might be excited on the test bed with input test functions while monitoring output values. Well-known methods, such as correlation techniques, Fourier analysis, and pulse or step response, apply here. Unfortunately, off-line techniques poorly cover most nonlinear, time-variant automotive applications. Even in cases where fixed parameters might be a good start, an automated offset for manufacturing tolerances and aging is required. Therefore, recursive on-line estimation procedures are favored in conjunction with adaptive control. Out of a large variety of recursive on-line estimation methods, only a few are suitable for automotive applications. Contrary to chemical processes, time constants within the engine, transmission, and antiskid brake systems are orders of magnitude smaller, starting in the range of only milliseconds. Therefore, algorithms for parameter estimation must converge very rapidly At the same time, closed-loop stability must be maintained. Further complicating the situation, limited performance even of future microcontrollers constrains computational complexity of estimation algorithms.

at steady speeds. Cruise control is a system that automatically controls the speed of an automobile.

1.5) ADAPTIVE AND ROBUST CONTROL

Assuming the existence of a model with sufficiently accurate parameters, adaptive control schemes can be applied. Robust control is another way to regulate plants with only slight parameter variations, if a controller with constant parameters is acceptable. I have investigated an adaptive cruise control for vehicles, which relieves the driver from regulation at a given speed. For different engine types, transmission gears, and loading conditions, plant parameters vary significantly. Characteristics of engine output torque and air drag are nonlinear. Conventional proportional-integral control performs rather poorly in this situation. **A** model for cruise control. Here, **KE** is the amplification factor of the engine torque map determined by testbed measurements, i, and **iA** the transmission ratios of the gearbox and the drivetrain, the transmission efficiency, and **r** the wheel radius.

The subtraction of different load forces from the driving force **Fd** yields the accelerating force **Fb,** which is integrated into portional to the effective mass of the vehicle, which also covers rotational movements **of** the drivetrain. The air drag force is calculated from the vehicle speed **v,** the wind velocity **v,,** the air density **pL,** the drag coefficient c,, and the sectional area A. Intelligent Control Controller synthesis as discussed thus far in this paper has been based on analytical models. Design methods have been aimed at optimization of a cost function, guarantee of stability, reassignment of dynamic behavior, etc.

1.5) CRUISE CONTROL

Cruise control (sometimes known as speed control in some countries) is a system that automatically controls the speed of a motor vehicle. Previously it was done by the governor who adjusts the throttle position as the speed of the engine changes with different loads. Following the 1973 oil crisis and rising fuel prices, the device became more popular in the U.S. "Cruise control can save gas by avoiding surges that expel fuel" while driving driver sets the speed and the system takes over the throttle of the car to maintain the speed. The system thereby improves driver comfort in steady traffic conditions. In congested traffic conditions, where speeds vary widely, these systems are no longer effective. Most cruise control systems do not allow the use of cruise control below a certain speed.

The driver must bring the vehicle up to speed manually and use a button to set the cruise control to the current speed. The cruise control takes its speed signal from a rotating driveshaft, speedometer cable, wheel speed sensor from the engine's RPM, or from internal speed pulses produced electronically by the vehicle. Most systems do not allow the use of the cruise control below a certain speed (normally around 25 mph). The vehicle will maintain the desired speed by pulling the throttle cable with a solenoid, vacuum driven servomechanism, or by using the electronic systems built into the vehicle (fully electronic) if it uses a 'drive-by-wire' system.

On the latest vehicles fitted with electronic throttle control, cruise control can be easily integrated into the vehicle's engine management system. Modern "adaptive" systems (see below) include the ability to automatically reduce speed when the distance to a car in front or the speed limit, decreases. This is an advantage for those driving in unfamiliar areas.

The cruise control systems of some vehicles incorporate a "speed limiter" function, which will not allow the vehicle to accelerate beyond a pre-set maximum; this can usually be overridden by fully depressing the accelerator pedal. (Most systems will prevent the vehicle accelerating beyond the chosen speed, but will not apply the brakes in the event of over speeding downhill).

Assuming the existence of a model with sufficiently accurate parameters, adaptive control schemes can be applied. Robust control is another way to regulate plants with only slight parameter variations, if a controller with constant parameters is acceptable.

A model for cruise control is shown in Fig.. Here, KE is the amplification factor of the engine torque map determined by tested measurements, iG, and iA the transmission ratios of the gearbox and the drive train, 7, the transmission efficiency, and r the wheel radius. The subtraction of different load forces from the driving force Fd yields the accelerating force Fb, which is integrated into vehicle speed v, The time constant T, is pro- portional to the effective mass of the vehicle, which also covers rotational movements of the drive train. The air drag force is calculated from the vehicle speed v, the wind velocity v, the air density pL, the drag coefficient c, and the sectional area A.

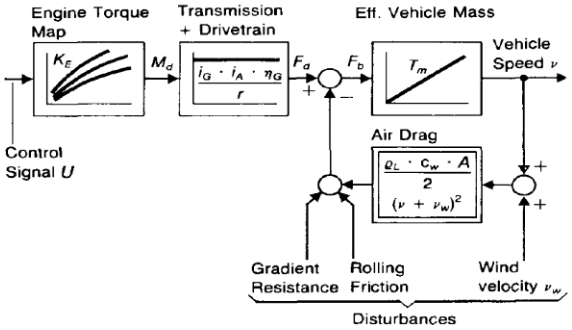


Fig. 2. Cruise Control Method

II. PROGRAMMABLE LOGIC CONTROLLER (PLC)

A programmable logic controller (PLC) or programmable controller is a digital computer used or automation of electromechanical processes, such as control of machinery on factory assembly lines, amusement rides, or lighting fixtures. PLCs are used in many industries and machines. Unlike general-purpose computers, output arrangements, extended temperature ranges, immunity to electrical noise, and resistance to vibration and impact. Programs to control machine operation are typically stored in battery-backed or non-volatile memory. A PLC is an example of a *hard* real time system since output results must be produced in response to input conditions within a bounded time, otherwise unintended operation will result.

The PLC was invented in response to the needs of the American automotive manufacturing industry. Programmable logic controllers were initially adopted by the automotive industry where software revision replaced the re-wiring of hard-wired control panels when production models changed. Before the PLC, control, sequencing, and safety interlock logic for manufacturing automobiles was accomplished using hundreds or thousands of relays, cam timers, and drum sequencers and dedicated closed-loop controllers. The process for updating such facilities for the yearly model change-over was very time consuming and expensive, as electricians needed to individually rewire each and every relay.

III. PROGRAMMING OF PLC

Early PLCs, up to the mid-1980s, were programmed using proprietary programming panels or special-purpose programming terminals, which often had dedicated function keys representing the various logical elements of PLC programs. Programs were stored on cassette tape cartridges. Facilities for printing and documentation were very minimal due to lack of memory capacity. The very oldest PLCs used non-volatile magnetic core memory. More recently, PLCs are programmed using application software on personal computers. The computer is connected to the PLC through Ethernet, RS-232, RS-485 or RS-422 cabling. The programming software allows entry and editing of the ladder-style logic.

Generally the software provides functions for debugging and troubleshooting the PLC software, for example, by highlighting portions of the logic to show current status during operation or via simulation. The software will upload and download the PLC program, for backup and restoration purposes. In some models of programmable controller, the program is transferred from a personal computer to the PLC though a programming board which writes the program into a removable chip such as an EEPROM or EPROM.

IV. FUNCTIONALITY OF PLC

The functionality of the PLC has evolved over the years to include sequential relay control, motion control, process control, distributed control systems and networking. The data handling, storage, processing power and communication capabilities of some modern PLCs are approximately equivalent to desktop computers. PLC-like programming combined with remote I/O hardware, allow a general-purpose desktop computer to overlap some PLCs in certain applications. Regarding the practicality of these desktop computer based logic controllers, it is important to note that they have not been generally accepted in heavy industry because the desktop computers run on less stable operating systems than do PLCs, and because the desktop computer hardware is typically not designed to the same levels of tolerance to temperature, humidity, vibration, and longevity as the processors used in PLCs. In addition to the hardware limitations of desktop based logic, operating systems such as Windows do not lend themselves to deterministic logic execution, with the result that the logic may not always respond to changes in logic state or input status with the extreme consistency in timing as is expected from PLCs. Still, such desktop logic applications find use in less critical situations, such as laboratory automation and use in small facilities where the application is less demanding and critical, because they are generally much less expensive than PLCs.

In more recent years, small products called PLRs (programmable logic relays), and also by similar names, have become more common and accepted. These are very much like PLCs, and are used in light industry where only a few points of I/O (i.e. a few signals coming in from the real world and a few going out) are involved, and low cost is desired. These small devices are typically made in a common physical size and shape by several manufacturers, and branded by the makers of larger PLCs to fill out their low end product range. Popular names include PICO Controller, NANO PLC, and other names implying very small controllers. Most of these have between 8 and 12 digital inputs, 4 and 8 digital outputs, and up to 2 analog inputs. Size is usually about 4" wide, 3" high, and 3" deep. Most such devices include a tiny postage stamp sized LCD screen for viewing simplified ladder logic (only a very small portion of the program being visible at a given time) and status of I/O points, and typically these screens are accompanied by a 4-way rocker push-button plus four more separate push-buttons, similar to the key buttons on a VCR remote control, and used to navigate and edit the logic. Most have a small plug for connecting via RS-232 or RS-485 to a personal computer so that programmers can use simple Windows applications for programming instead of being forced to use the tiny LCD and push-button set for this purpose. Unlike regular PLCs that are usually modular and greatly expandable, the PLRs are usually not modular or expandable, but their price can be two orders of magnitude less than a PLC and they still offer robust design and deterministic execution of the logic.

4.1) BUS/CONNECTOR FOR CONNECTING IO & OTHER MODULES

Key Pad for programming(only on small PLC eg:LOGO of Siemens) LEDs for indicating input & output status. Hardware interface for communication with programming device or HMI:RS232/RS485/RJ45 etc. Each CPU has inbuilt software protocol required for communication such as Ethernet, Modbus, Profibus DP etc.

4.2) DIGITAL INPUTS

Field status and process data is provided to the CPU by on board inputs or via input signal modules. Power supply required for these modules is provided by the CPU. There is a limitation to how many expansion modules can be connected to the CPU as there is a limit on the current that can be provided by the CPU for the modules.(via back-plane bus).Power supply needed for the inputs has to be supplied additionally. Inputs to PLC can be digital and analog inputs.

4.3) DIGITAL OUTPUTS

Following points should be considered while using digital outputs of PLC. Type of output Relay type Transistorized Frequency of outputs. Voltage range for 0 and 1 signal (0-5V for 0 /15-24 for 1) number of on board outputs/outputs on expansion modules

4.4) ANALOG INPUTS

- Analog inputs are the signals which have a particular range from some minimum to maximum value such as Type of analog input: 0-10V,0-20mA, 4-20mA, Temperature sensors like RTD(ohms) & TC(mV) etc. Expansion capability for analog input(Max.number of analog inputs that can be connected) Value of the data word(32000,27648 etc) Resolution(11bits,12 bits etc)

4.5) ANALOG OUTPUTS

Following points should be considered while using analog outputs of PLC.

- Type of analog output:0-10V,0-20mA,4-20mA etc.

Expansion capacity of analog outputs

- Type of analog output:0-10V,0-20mA,4-20mA etc.

Expansion capacity of analog outputs Value of the data word(32000,27648 etc)

- Resolution(11bits,12 bits etc)
- Communication Modules

Communication modules enables communication of PLC with the devices having different hardware interfaces (RS232,RS485,RJ45 etc) and different software protocols such as Modbus, Profibus, Ethernet etc. Devices like Barcode Scanner, Printer, HMI, Drive etc can be communicated with the PLC using such modules. PLC programming software provides special functions for communication with these kind of devices. Following points should be considered while giving analog inputs to PLC.

4.6) COMPONENTS OF PLC

- Power Supply
- CPU
- Digital Input Module
- Digital Output Module
- Analog Input Module
- Analog Output Module
- Function Module
- Communication Processors
- Programming and Communication Cable
- Programming device with programming software installed

V. SUMMARY

This chapter has described the design objectives of the project into further detail, given the vehicle model that will be representing a real vehicle in this project, presented designs of the CRUISE CONTROL controllers, and proposed a way to rate the performance and an approach to tune the controllers. The contents are summarised here. In short, the CRUISE CONTROL controllers to be designed as part of the project goal are PLC-based as well as PLC-based CRUISE CONTROL controllers, with for each of these controller types three information gathering configurations, one that only looks at the direct predecessor for its reference, one that looks at its first two direct chapter first describes the simulation setup, after which the scenarios used to tune the controllers with are given and the tuning results are presented. The final section then evaluates the tuned controllers.

VI. CASE STUDY

The CRUISE CONTROL controllers and implemented into simulated vehicles that are part of a simulation of a platoon of vehicles. The controllers will be tuned and evaluated using this simulation setup. They are not evaluated with real vehicles, because that is beyond the scope of this project. The simulation consists of a main simulation function in SIMATIC MANAGER

VII. EVALUATION

7.1) RESULTS FROM SIMULATING DIFFERENT SCENARIOS

To be able to evaluate the CRUISE CONTROL controllers that have been designed, they are implemented in a platoon of vehicles that undergoes two traffic scenarios, each of which is composed of several subsequent subscenarios. The first scenario, which will be called scenario 1, is the scenario used for tuning of the PLC-based controllers (again with five vehicles)11. The second scenario (the validation scenario, scenario 2) is built up from similar types of subscenarios, but with different values for velocity and acceleration. Because this scenario is onl no need for it to be small. Furthermore, the longer the platoon and the more different situations are simulated, the better the controllers can be

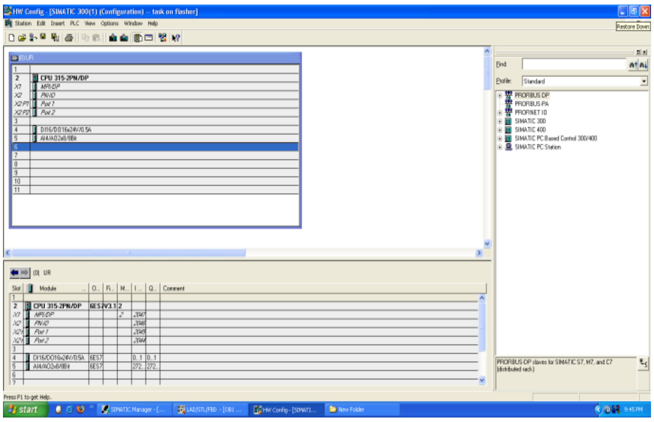
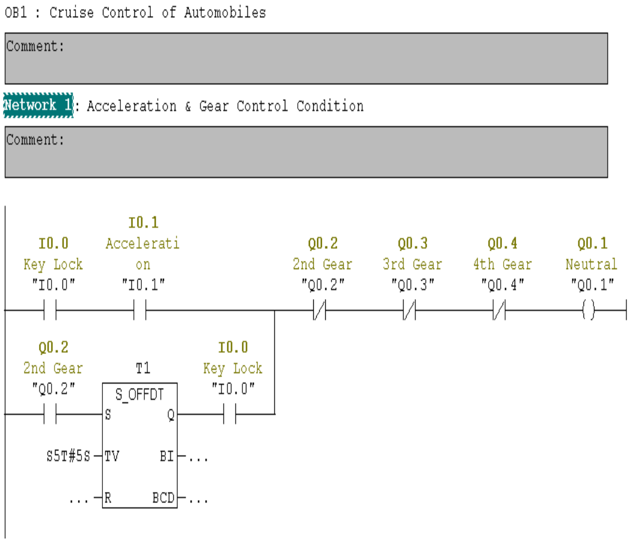


Fig. 3. Hardware Configuration

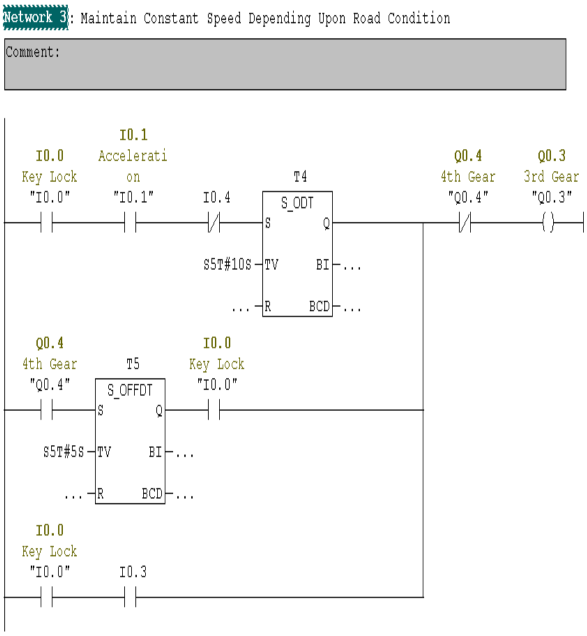

OB1 : Cruise Control of Automobiles

Comment:

Network 1: Acceleration & Gear Control Condition

Comment:

Fig. 4. Acceleration & Gear Control Condition


Network 3: Maintain Constant Speed Depending Upon Road Condition

Comment:

Fig. 5. According to Road Condition

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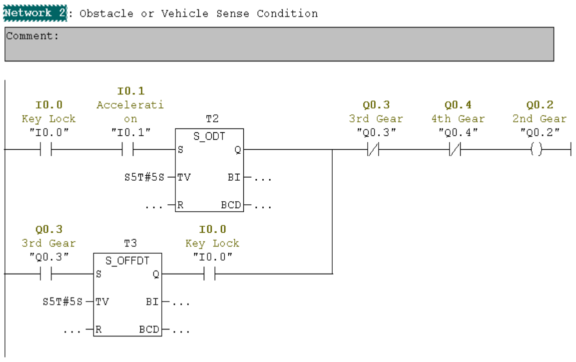

Fig. 6. Obstacle or Vehicle Sense Condition

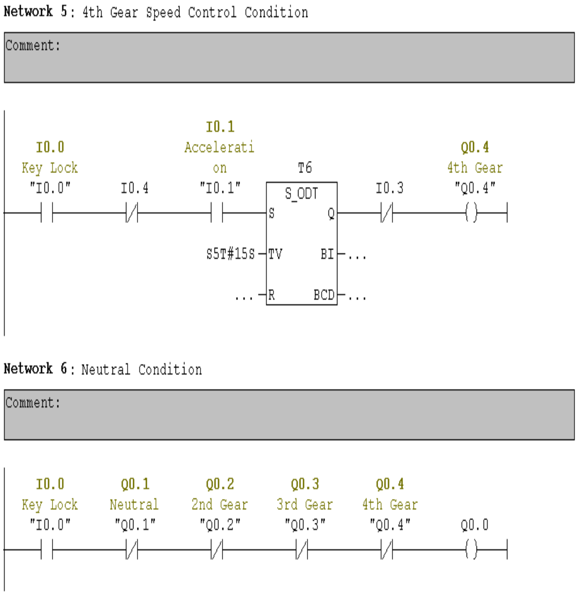

Fig. 7. Speed Control &Neutral Condition

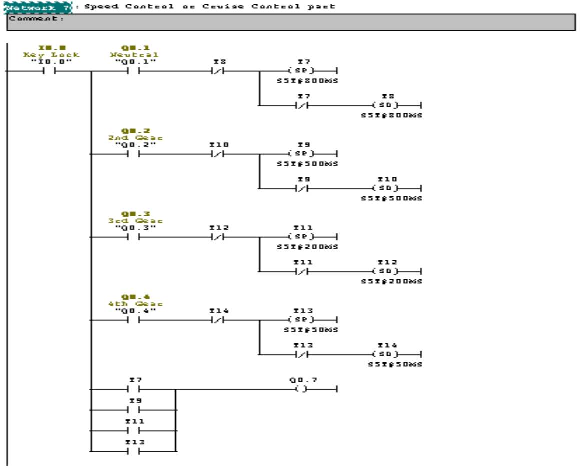

Fig. 8. Cruise Control Method

VIII. CONCLUSION

In order to improve performance of automatic control in automotive systems, more advanced control schemes involving modeling, parameter and state estimation, and adaptation will be applied. An overall optimization layer combining all electronic systems will further improve driving safety and economy. To handle nonlinear and time varying automotive systems, additional progress in control engineering is needed, especially in the areas of state-variable estimation and intelligent control.

1. PLC-based CRUISE CONTROL is safer than other CRUISE CONTROL, and therefore preferred as a control method for CRUISE CONTROL.. Furthermore, with respect to designing CRUISE CONTROL controllers, based on the case study the following conclusion can be formulated:

2. It is not easy to design a CRUISE CONTROL controller that obtains smooth throttle/ brake trajectories with PLC. With PLC this seems easier to achieve, but at the cost of a slower platoons. Because safety is more important than comfort.

3. With PLC-based CRUISE CONTROL it is preferred to receive through communication, in addition to the current states of the direct predecessor, at least the current states of the second predecessor and/or the predicted future states from the direct predecessor, in order to achieve better string stability. The right tuning of the weight factor that punishes throttle/brake increments as part of the PLC performance index is very important, because the results from the case study showed how too low a value for this weight can cause sudden peaks and oscillation in acceleration. Because too high a value of this weight could give other problems (e.g., low responsiveness to braking predecessors, possibly causing the need for excessive braking later on, past the initial prediction horizon), it is not easy to find the right value for it. With PLC the observed throttle/ brake trajectories were much smoother. But it should be noted that in order to achieve this, the acceleration gain after tuning was negligible.

This also resulted in a slow response, which in turn, resulted in the need for a large headway for the second vehicle in the platoon, and in the fact that this vehicle still could not avoid a crash during the validation scenario.In order to improve performance of automatic control in automotive systems, more advanced control schemes involving modeling, parameter and state estimation, and adaptation will be applied. An overall optimization layer combining all electronic systems will further improve driving safety and economy. To handle nonlinear and time varying automotive systems, additional progress in control engineering is needed, especially in the areas of state-variable estimation and intelligent control.

Therefore, it is expected that PLC-based CRUISE CONTROL can also be safe for larger platoons because safety is more important than comfort.

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This project could only have been carried out the kind assistance of colleagues, family and friends. I would like to thank my guide/supervisor Asst. Prof. Linkan Priyadarshini, Department of Electrical & Electronics Engineering for his support and guidance throughout this project and for his patience and understanding on a more personal level. I was fortunate to be able to profit from his skills, not only in the systems & control theory & research in the field but also his through knowledge of the English language and his precision.

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