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# Air/Fuel Ratio Control in Diesel-Dual-Fuel Engine by Varying Throttle, EGR Valve, and Total Fuel

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## ABSTRACT

From our experiences in converting diesel engine into diesel-dual-fuel engine with natural gas as primary fuel, accurate air/fuel ratio control is vital to the high engine performance, good vehicle drivability, and low emissions. Two components enter in calculating the air/fuel ratio, namely, the amount of fresh air and the amount of diesel and natural gas. Throttle and EGR valve are two actuators directly affect the amount of air, and the desired total fuel determines how much fuel should be injected at an instance. As opposed to inactive, fully opened throttle in typical diesel engine, the throttle in diesel-dual-fuel engine is regulated to cover wider range of desired air/fuel ratio. As a result, the problem of controlling the amount of air in diesel-dual-fuel engine becomes that of multi variables in which both throttle and EGR valve are involved. We present a novel algorithm that breaks the multi-variable control problem into two single-variable problems. The throttle and EGR valve are regulated one at a time as determined by a switch-and-hold logic that optimizes the throttle opening to reduce pumping loss. An algorithm is also proposed to prevent the throttle from fully closed. Because the fuel path is much faster than the air path, including in the algorithm is the adjustment of the desired total fuel according to the air/fuel ratio tracking error. We found that adjusting the total fuel within a limit helps improve the transient response. Experiments were performed on an engine test bed and a pickup truck; both engines were modified from four cylindrical diesel engines to run diesel-dual-fuel, where the natural gas is injected at each intake port. The test bed experiment showed that the air/fuel ratio was accurately regulated with widest range possible. The pickup truck was commanded to follow the new European driving cycle. The results showed that the throttle opening was optimized at all time.

## INTRODUCTION

Due to the steeper price of diesel and gasoline, alternate and lower price fuel such as compressed natural gas (CNG) has become more attractive to the users. Recently, CNG has been successfully used in spark-ignition (SI) engines such as those running bi-fuels. With spark-assisted ignition, using CNG does not post much practical problems.

Compared to the spark-ignition engine of the same size, compressed-ignition (CI) engine has higher fuel efficiency and performance, which makes it more preferable for heavy-duty trucks. Due to physical limitations, CI engines cannot run with CNG alone. A customary modification is to inject CNG in the intake ports and to inject a smaller amount of diesel directly in the cylinder to initiate the combustion. This so-called diesel-dual-fuel (DDF) engine has a prospect of converting existing diesel trucks to run partly on CNG. Our experiences have shown that obtaining from CNG 60-70 percents by energy is possible.

However, DDF engine controls become more challenging both in air and fuel paths because the engine now uses two fuels at the same time. CNG is injected at the intake ports similar to the typical SI engine, while diesel is injected in the cylinder as is done in the CI engine. DDF engine therefore has combined characteristics of SI and CI engines.

In CI engine, throttle is usually inactive and fully opened for maximum fresh-air intake, and exhausted gas recirculated (EGR) valve and variable geometry turbine (VGT) are actuated to bring portion of the exhausted gas back to the cylinder to reduce temperature and therefore reduce NOx. In SI engine, throttle is usually very active in achieving lambda one, while EGR valve and VGT are normally not required due to lower-temperature combustion chamber.

In DDF engine, throttle, EGR valve, and VGT are all actively actuated. For low emissions, the engine must follow a desired air/fuel ratio closely. This desired air/fuel ratio, found during calibration, has wider range than those of SI and DI engines. Since throttle is not fully opened as in CI engine, to reduce pumping loss, the throttle must be opened as wide as possible, while still follows a desired air/fuel ratio.

Existing literature on air/fuel ratio control of DDF engine is either non-existent or unavailable. Since in SI engine, throttle is normally driven by driver's pedal, and its air path is not actively controlled, we surveyed instead the air path control of the CI engine.

The first group formulated the air path control problem as multivariable problem and solved using $H_\infty$-based optimization algorithms. Ref. [1] applied the $H_\infty$ mixed synthesis and a controller based on internal model principle to control the air/fuel ratio of diesel engine by actuating only the EGR valve. Ref. [2]-[3] formulated a multivariable problem in controlling the air path of a turbocharged diesel engine, where the plant has two inputs, EGR position and variable geometry turbine (VGT) position, and two outputs, mass air flow (MAF) and manifold pressure (MAP). Their control techniques are two-degree-of-freedom $H_\infty$ loop-shaping. Both the $H_\infty$ mixed synthesis and $H_\infty$ loop-shaping techniques are covered excellently in [4]. An extension to control design based on linear parameter varying (LPV) model can be found in [5].

Additional optimization algorithms that are closely related to the $H_\infty$ algorithm are as follows. Ref. [6]-[7] formulated a gain-scheduling $H_\infty$-based control. The scheduled variables are engine speed, VGT position, and MAP. The plant model is in quasi linear parameter varying (LPV) form, with two inputs as EGR and VGT positions and two outputs as MAF and MAP. Ref. [8] presented a linear matrix inequality (LMI) based control, where a nonlinear plant having EGR valve and VGT openings as inputs and EGR flow and air/fuel ratio as outputs was formulated. Around each operating point, the plant was linearized and put in polytopic form. Ref. [9] applied LQG to controlling air/fuel ratio and burned gas fraction by regulating EGR valve and VGT. Several decentralized controls were presented in [10] to regulate MAP and MAF by actuating the EGR valve and VGT.

The second group designed air path controller from nonlinear model using several nonlinear control techniques. Ref. [11] applied the dynamic feedback linearization to control of the turbocharged diesel engine air path. EGR and VGT flows were used as plant inputs. For plant outputs, instead of using EGR fraction and air/fuel ratio or MAP and MAF, they used MAP and a modified signal, a function of MAP, exhaust manifold pressure, and compressor power, as their outputs. The reasons for this choice are signal accessibility in commercial vehicle and avoiding non-minimum-phase plant model. Ref. [12] treated fuel amount and VGT position as inputs and air/fuel ratio as output. The control design was based on the backstepping control. Ref. [13] applied sliding mode control in controlling the air/fuel ratio and EGR rate using EGR valve and VGT positions. Ref. [14] used constructive Lyapunov control in regulating the air/fuel ratio and EGR fraction by actuating the EGR valve and VGT.

A simple linear control using observer can be seen in [15], which presented an output-feedback PID control, having EGR valve and VGT openings as plant inputs and MAP and EGR fraction as plant outputs. A Luenberger-type observer was used to estimate EGR flow.

The third group used favorable properties of model predictive control in dealing with input and output constraints. Ref. [16] applied model predictive control to control MAF and MAP having EGR valve and VGT as controlled inputs and engine speed and load as disturbance inputs. Active set strategy was used to reduce computational time, which makes the algorithm implementable in real time. Ref. [17] used lookup tables to obtain set points for air/fuel ratio and the amount of recirculated exhaust gas from engine speed and fueling rate. Set points for MAP, exhaust manifold pressure, and compressor power were then determined from the two set points via formulas. The EGR valve and VGT were commanded to track the set points. A nonlinear model predictive control was used for tracking the set points and for constraining the EGR valve and VGT openings to physical limits.

Since the amount of air inside of the cylinders directly affects the combustion. Several researchers have designed air estimators and included them in their algorithms. In real-time, Ref. [18] used recursive least square algorithm to estimate air/fuel ratio in each cylinder using a single UEGO sensor placed at the exhaust pipe. The estimated air/fuel ratio was then used in an optimal control algorithm to control individual fuel injector to obtain desired air/fuel ratio in each cylinder. Ref. [19] used Kalman filter in estimating the air/fuel ratio in each cylinder from a single air/fuel ratio measurement at turbine downstream.

Not many work discussed pumping loss. In [20], the VGT was actuated together with the EGR valve to control oxygen-to-fuel ratio and EGR fraction of diesel engine. Both actuators were designed to minimize pumping loss, which was defined to be the difference between exhaust manifold and intake manifold pressures.

Also not many work actuated the fuel injector, in addition to the EGR valve and VGT, to control air/fuel ratio. Ref. [21] used fuzzy logic control in adjusting diesel fuel injector's pulse width to track desired air/fuel ratio, while EGR valve and VGT were commanded to follow pre-specified maps.

In this paper, the plant has three inputs, which are total fuel, throttle opening, and EGR valve opening, and one output, which is the air/fuel ratio. A novel switch-and-hold logic is designed to actuate either throttle or EGR valve, one at a time, by opening the throttle as wide as possible at all time to reduce pumping loss, while still achieving the air/fuel ratio set point. This reduces the multivariable problem to two single variable problems, which can be controlled by any advanced control algorithms suitable for single variable problem.

There are three control schemes in this paper. In the first scheme, tracking error, which is the difference between actual air/fuel ratio and its set point, drives throttle and EGR valve directly by affecting the PWM duty cycle sent to the electromagnetic valves. Due to deadzone and hysteresis, this scheme is difficult to keep the valves open at small angles.

As a remedy to this problem, in the second scheme, the tracking error is first converted to set points from which the throttle and EGR valve are commanded to follow. By this way, a lower limit can easily be placed on the desired opening angles.

In the third scheme, the total fuel is adjusted, in addition to the throttle and EGR valve, to help in following the set point especially during fast set point changes such as in transients. This is because the dynamic of the fuel path is usually faster than that of the air path.

Experimental results are obtained from two DDF engines, modified from two 2KD-FTV Toyota CI engines by injecting CNG at each intake port to each cylinder. One engine is used as a test bed with an engine dynamometer; the other one is installed in a Toyota pick-up truck. The test bed was commanded to follow step change in set point, and the pick-up truck to follow the new European driving cycle (NEDC). Experimental results show the effectiveness of the control system.

The content of this paper is divided into four sections, which are introduction, control system design, experimental results, and conclusions. We have presented the introduction in this section. In control system design section to follow, we present the switch-and-hold logic and the overall air-fuel ratio control algorithm including its modification. Then, in the experimental results section, various implementation results on a pick-up truck and an engine test bed are presented. The paper is closed with a conclusions section followed by all the necessary back matters.

## CONTROL SYSTEM DESIGN

In DDF engine, typical diesel engine is modified to inject the CNG at the intake ports of each cylinder. Figure 1 is a simplified diagram of the air-path system with the addition of a mass-air-flow (MAF) sensor to measure intake air mass. The intake air mass signal is sent to the electronic control unit (ECU) to calculate the air/fuel ratio and to compute control efforts for throttle, EGR valve, and diesel and CNG injectors.

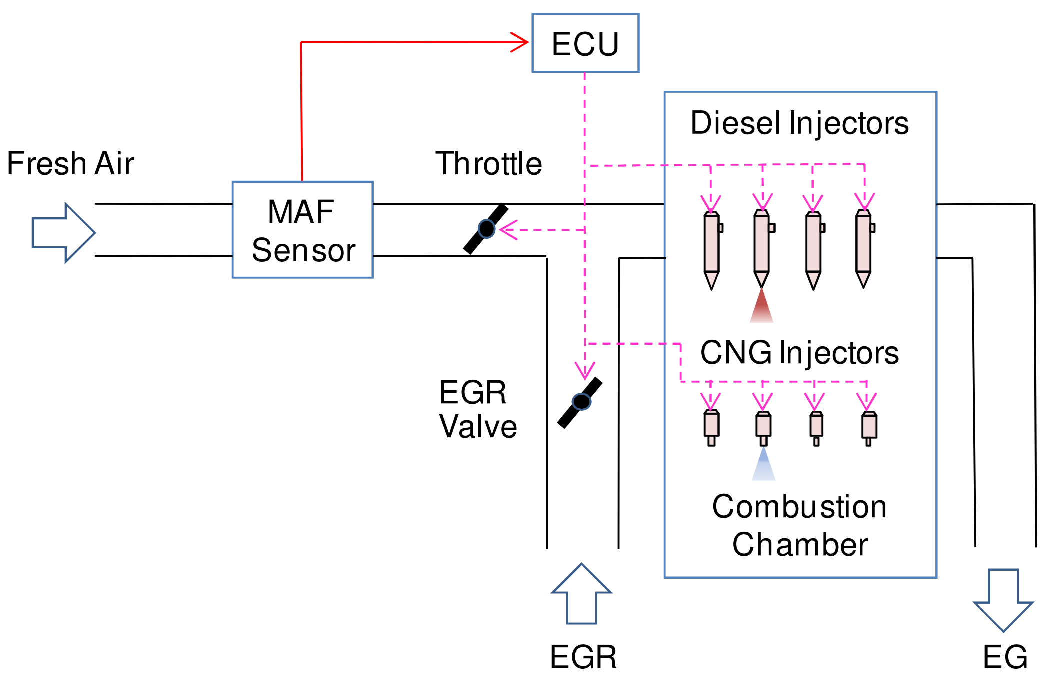


Figure 1: Air-path system with pertaining sensors and actuators.

The air/fuel ratio is computed according to the formula

$$\lambda = \frac{(A/F)_{actual}}{(A/F)_{stoi}} = \frac{\left(\frac{A}{F_g + F_d}\right)}{R(A/F)_g + (1-R)(A/F)_d}, \quad (1)$$

where $\lambda$ is the air/fuel ratio, $A$ is quantity of air actually used, $F_g$ is quantity of CNG actually used, $F_d$ is quantity of diesel actually used, $R$ is replacement ratio, which is the ratio between the CNG mass and total fuel mass, $(A/F)_g$ is a constant equals 16.3, and $(A/F)_d$ is a constant equals 14.6.

Desired air/fuel ratio $\lambda_d$ was obtained as a map from engine speed and indicated mean effective pressure (IMEP). Figure 2 shows the map of our DDF engine, tuned for high efficiency and performance and low emissions.

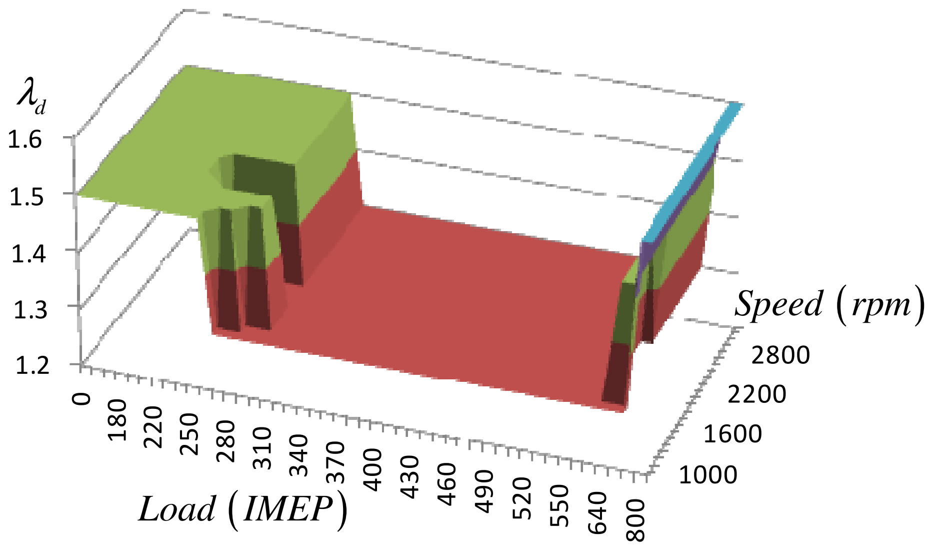


Figure 2: Map of the desired air/fuel ratio as a function of engine speed (rpm) and load (IMEP).

For pumping loss minimization, we aim to open the throttle as much as possible at all times. The optimum movement of the throttle and the EGR valve depend on current EGR valve position and current throttle position (TPS). Figure 3 contains two diagrams showing the optimum movement of the throttle. Figure 3(a) is for increasing the air/fuel ratio, and Figure 3(b) is for decreasing the air/fuel ratio. Two X symbols mark actuator positions where minimum and maximum achievable air/fuel ratios are obtained.

Notice that, in increasing the air/fuel ratio, higher priority is given to increasing the throttle opening. The EGR valve opening is decreased only after the throttle is opened fully. Maximum achievable air/fuel ratio occurs when the throttle is at maximum opening and the EGR valve is at minimum opening.

In decreasing the air/fuel ratio, we choose to increase the EGR valve opening first before decrease the throttle opening. This is to maintain the throttle opening as wide as possible. Minimum achievable air/fuel ratio occurs when the throttle is at minimum opening and the EGR valve is at maximum opening.

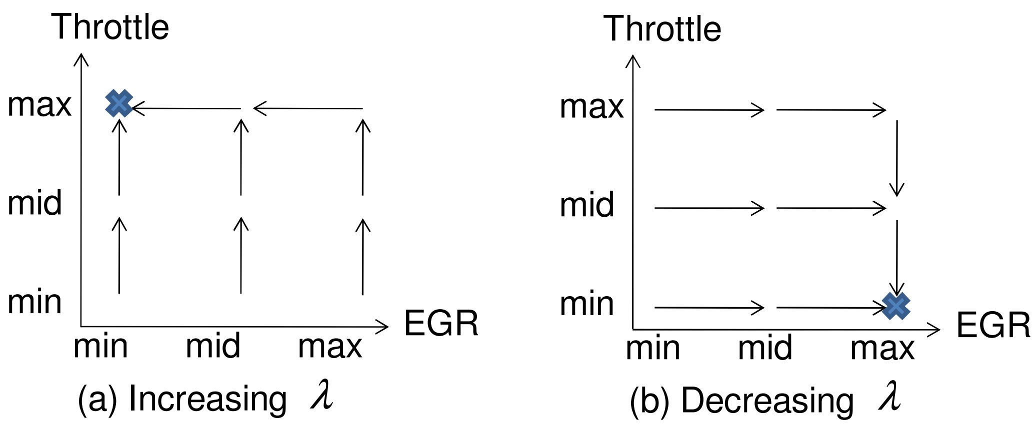


Figure 3: Desirable movements of the throttle and EGR valve in increasing and decreasing the air/fuel ratio.

Figure 4 depicts a block diagram of the air/fuel ratio control system, where tracking error directly affects PWM duty cycles used to actuate throttle and EGR valve. $\lambda$ is the actual air/fuel ratio computed on-line using (1), $\lambda_d$ is the desired air-fuel ratio obtained on-line from the map in Figure 2, $e$ is the tracking error, $G_T$ and $G_E$ are controllers for the throttle and the EGR valve whose outputs are $u_T$ and $u_E$ respectively, $P_T$ and $P_E$ represent the throttle and the EGR valve whose position outputs are $\theta_T$ and $\theta_E$ respectively. The measured output positions $\theta_T$ and $\theta_E$ are fed back to the switch-and-hold algorithm together with the tracking error $e$. The output from the switch-and-hold algorithm determines which actuator to be actuated.

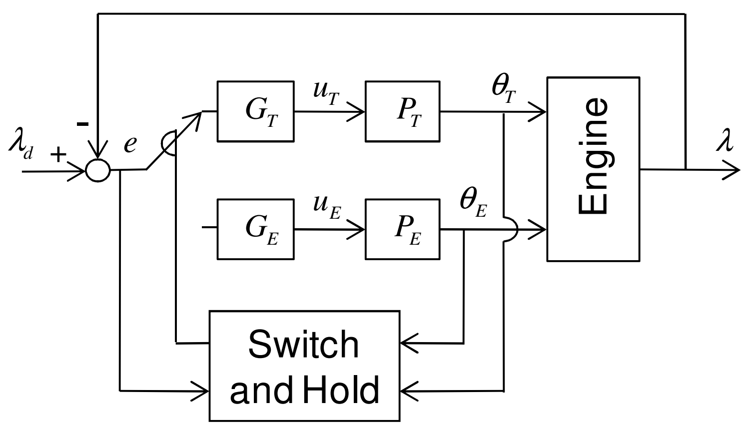


Figure 4: Air/fuel ratio control system where tracking error directly affects PWM duty cycles for throttle and EGR valve.

Following the logic in Figure 3, the switch-and-hold algorithm is as follows. The throttle is actuated and the EGR valve is held constant when either one of these happens: 1) $\lambda_d - \lambda > 0$ (must increase $\lambda$) and the throttle opening is not at maximum or 2) $\lambda_d - \lambda < 0$ (must decrease $\lambda$) and the EGR valve opening is at maximum. Or the EGR valve is actuated and the throttle is held constant when either one of these happens: 3) $\lambda_d - \lambda > 0$ (must increase $\lambda$) and the throttle opening is at maximum or 4) $\lambda_d - \lambda < 0$ (must decrease $\lambda$) and the EGR valve opening is not at maximum.

The set-up in Figure 4 is very active and can respond swiftly to the driver especially during transient operations. However, one disadvantage is that it is difficult to set a lower limit for the throttle opening. Normally, the throttle should not be fully closed to avoid high emission. Because of actuator's backlash and hysteresis and varying operating points, setting a constant lower limit at $u_T$ does not always guarantee that the throttle will not be fully closed.

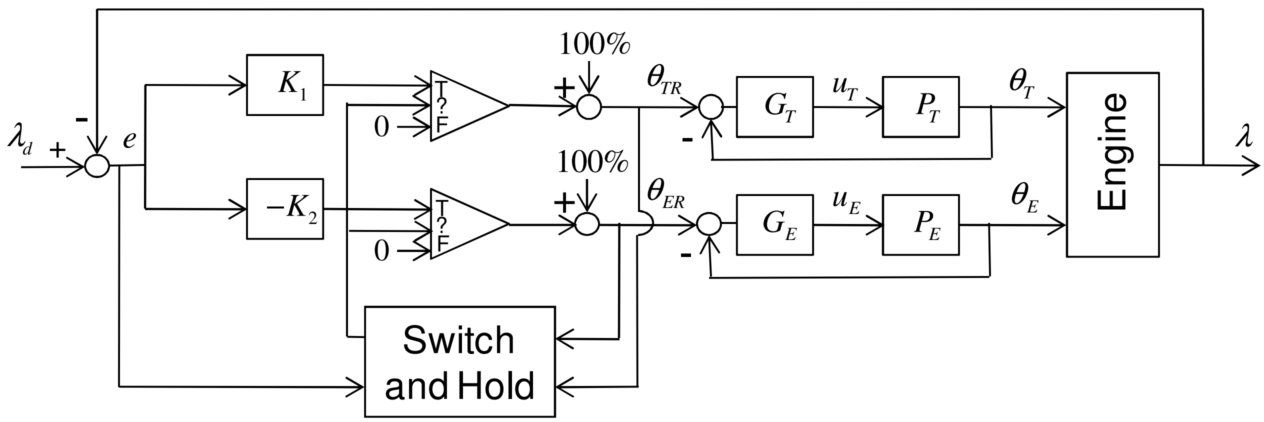


Figure 5: Air/fuel ratio control system where tracking error affects reference values for throttle and EGR valve openings.

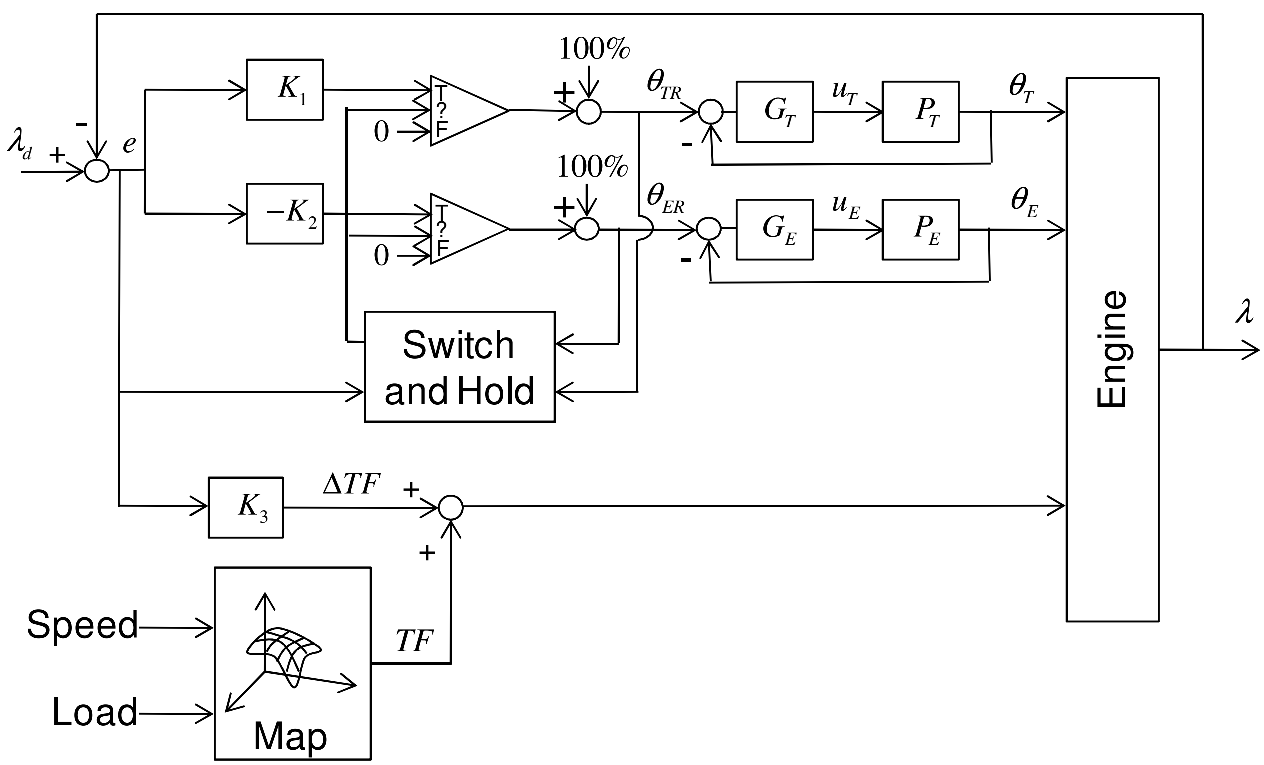


Figure 6: Air/fuel ratio control system where tracking error affects variation of total fuel and reference values.

Figure 5 contains a modification to avoid this problem. The tracking error $e$ is now used to create reference values $\theta_{TR}$ and $\theta_{ER}$ for the throttle and the EGR valve to follow. $K_1$ and $K_2$ are two positive constant gains, which can be of different values. $G_T$ and $G_E$ are two separated controllers to ensure that the throttle opening $\theta_T$

and the EGR valve opening $\theta_E$ track their reference values $\theta_{TR}$ and $\theta_{ER}$ closely. The set-up in Figure 5 has slower dynamic than that of Figure 4. However, minimum throttle and EGR openings can easily be enforced.

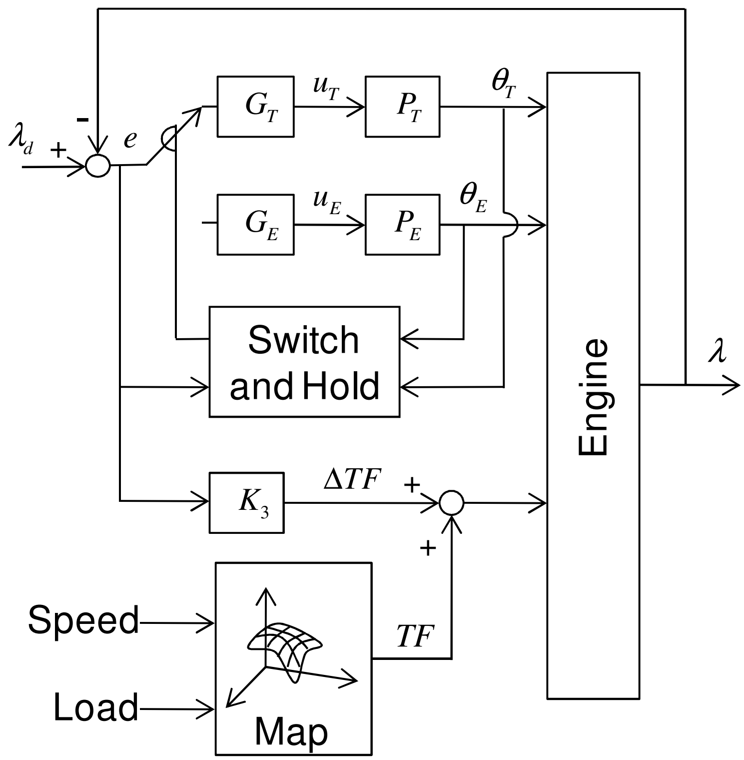


Figure 7: Air/fuel ratio control system where tracking error affects variation of total fuel and PWM duty cycles.

Because the fuel amount also affects the air/fuel ratio, another modification is to adjust total fuel amount. Figure 6 and Figure 7 show two modifications, where $TF$ is total fuel amount, determined during engine calibration as a function of speed and load, $\Delta TF$ is variation of $TF$ as a function of the tracking error, and the gain $K_3$ is a properly tuned positive constant. Figure 6 is when the total fuel amount adjustment is used together with change in reference values. Figure 7 is when the total fuel amount adjustment is used together with change in PWM duty cycles.

## EXPERIMENTAL RESULTS

We implemented the control algorithms in Figure 4 to Figure 7 to an engine test bed and a pick-up truck using the same engine model. The engine test bed was connected to an engine dynamometer, and the pick-up truck was connected to a chassis dynamometer. The engine was modified from a Toyota 2KD-FTV diesel engine to run diesel-dual-fuel by injecting 375 kPa CNG to each of the four intake ports. The distance from the CNG injector to the port is kept as small as possible at 25 cm to reduce time delay.

The engine has four cylinders, each of 2.5 liters, sixteen intake and exhausted valves with double overhead cam shaft (DOHC), a turbocharger with an EGR valve and a throttle but without variable geometry turbine (VGT), and common-rail direct fuel injection system.

The OEM ECU was replaced with an ECU whose hardwares are mainly from National Instruments. All control algorithms were written in Labview graphical programming language. A desktop computer acts as a host to communicate with human operator and is connected to a target running Labview Realtime and FPGA modules.

For simplicity two simple PID controllers were used as $G_T$ and $G_E$ for all algorithms. However, the PID controllers can easily be replaced by more advanced controllers, which might improve the tracking performance further. All the PID gains and the positive constants $K_1$, $K_2$, and $K_3$ were chosen from trial-and-error.

We first discuss the experimental results from the engine test bed, followed by the results from the pick-up truck. Figure 8 to Figure 11 include the experimental results from the engine test bed using the algorithms in Figure 4 to Figure 7, respectively. In all cases, the measured air/fuel ratio $\lambda$ was commanded to follow step changes in the desired air-fuel ratio $\lambda_d$ from 1.3 to 1.5.

Figure 8(a) contains plots of the measured air/fuel ratio (in solid line) and the desired air/fuel ratio (in dash line) versus time. The measured air/fuel ratio was able to follow the desired air/fuel ratio well at steady state, but with high overshoot and undershoot during transient. The response shows that the system has non-minimum phase, which can be seen from initial wrong direction of the measured air/fuel ratio in following the step changes of the desired air-fuel ratio. As a result of time delay commonly seen in applications involving gas flow, this non-minimum phase can hinder the control system if not dealt with. Figure 8(b) shows the throttle opening percentage (in solid line) and the EGR valve opening percentage (in dash line.) Both actuators operated as expected with the throttle opening well above the lower bound. The EGR valve opening was chattering, which is a result of too high $K_2$ gain. Figure 8(c) shows plot of total fuel, which is the addition of CNG and diesel (both in mg/stroke.) The algorithm in Figure 4 does not alter the total fuel, so it comes directly from the pre-specified map.

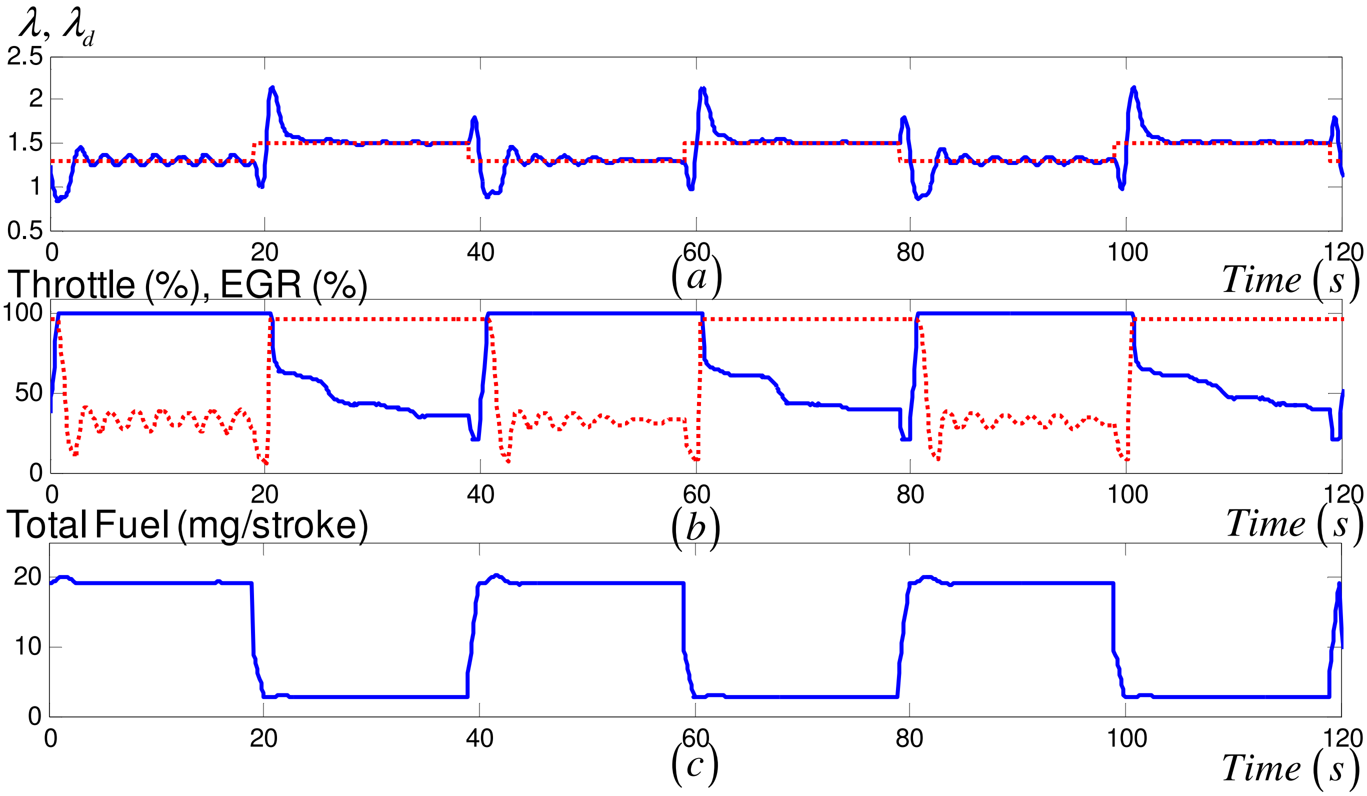


Figure 8: Set point changes test on an engine test bed using algorithm in Figure 4. (a) Actual lambda (solid line) and desired lambda (dash line.) (b) Throttle opening percentage (solid line) and EGR valve opening percentage (dash line.) (c) Total fuel.

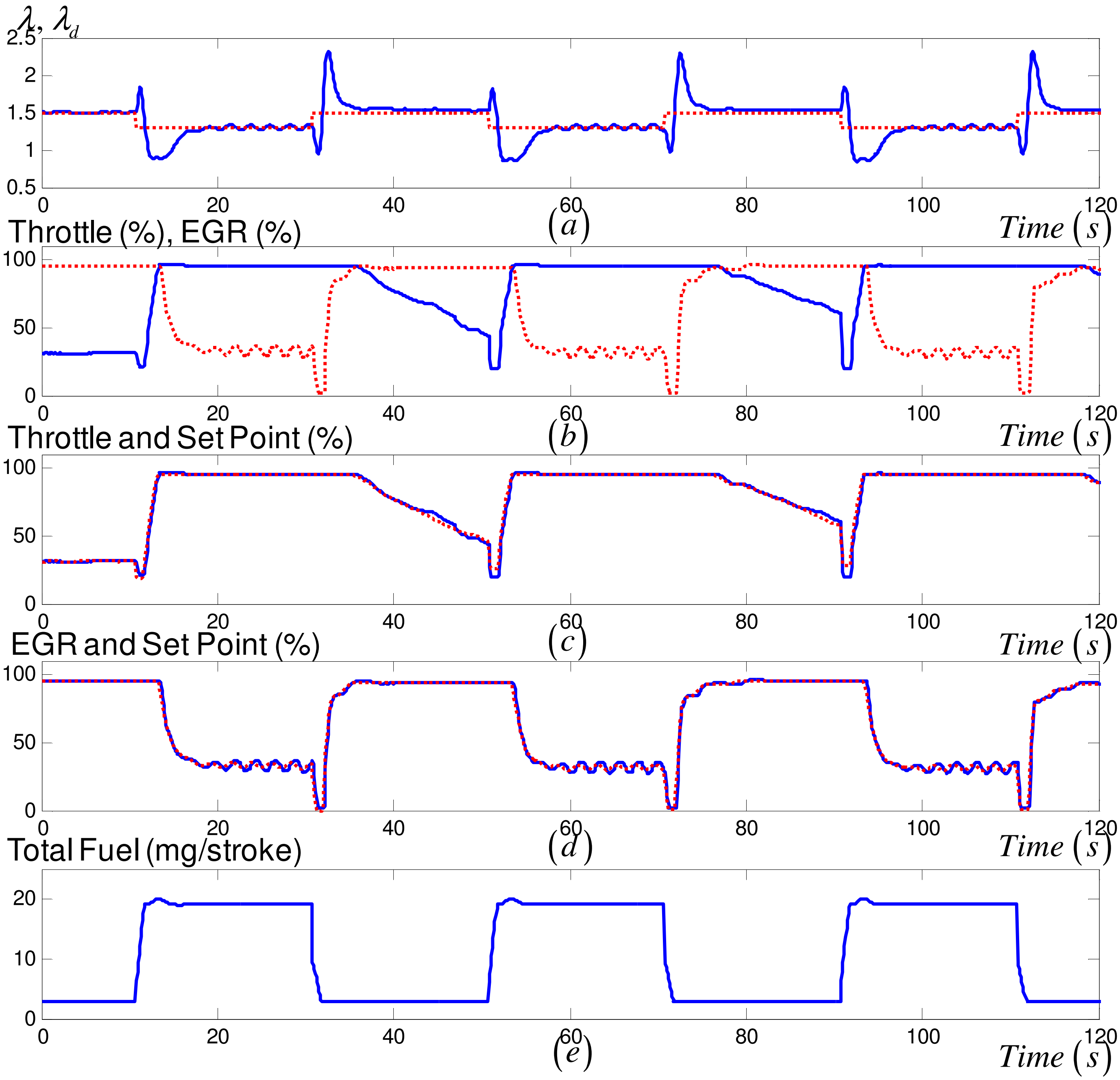


Figure 9: Set point changes test on an engine test bed using algorithm in Figure 5. (a) Actual lambda (solid line) and desired lambda (dash line.) (b) Throttle opening percentage (solid line) and EGR valve opening percentage (dash line.) (c) Throttle opening percentage (solid line) and its set point (dash line.) (d) EGR valve opening percentage (solid line) and its set point (dash line.) (e) Total fuel.

Figure 9 contains results of implementing the algorithm in Figure 5, where the tracking error affects the references of throttle and EGR valve. Figure 9(a) shows the desired and measured air/fuel ratios. Figure 9(b) shows throttle and EGR valve opening percentage. Figure 9(c) presents measured throttle opening percentage and its set point. Figure 9(d) presents measured EGR valve opening percentage and its set point. Figure 9(e) presents total fuel in mg/stroke. Similar results to those of Figure 8 can be seen. The measured air/fuel ratio still has high overshoot and undershoot. The throttle and EGR valve can follow their set points quite closely with simple PIDs.

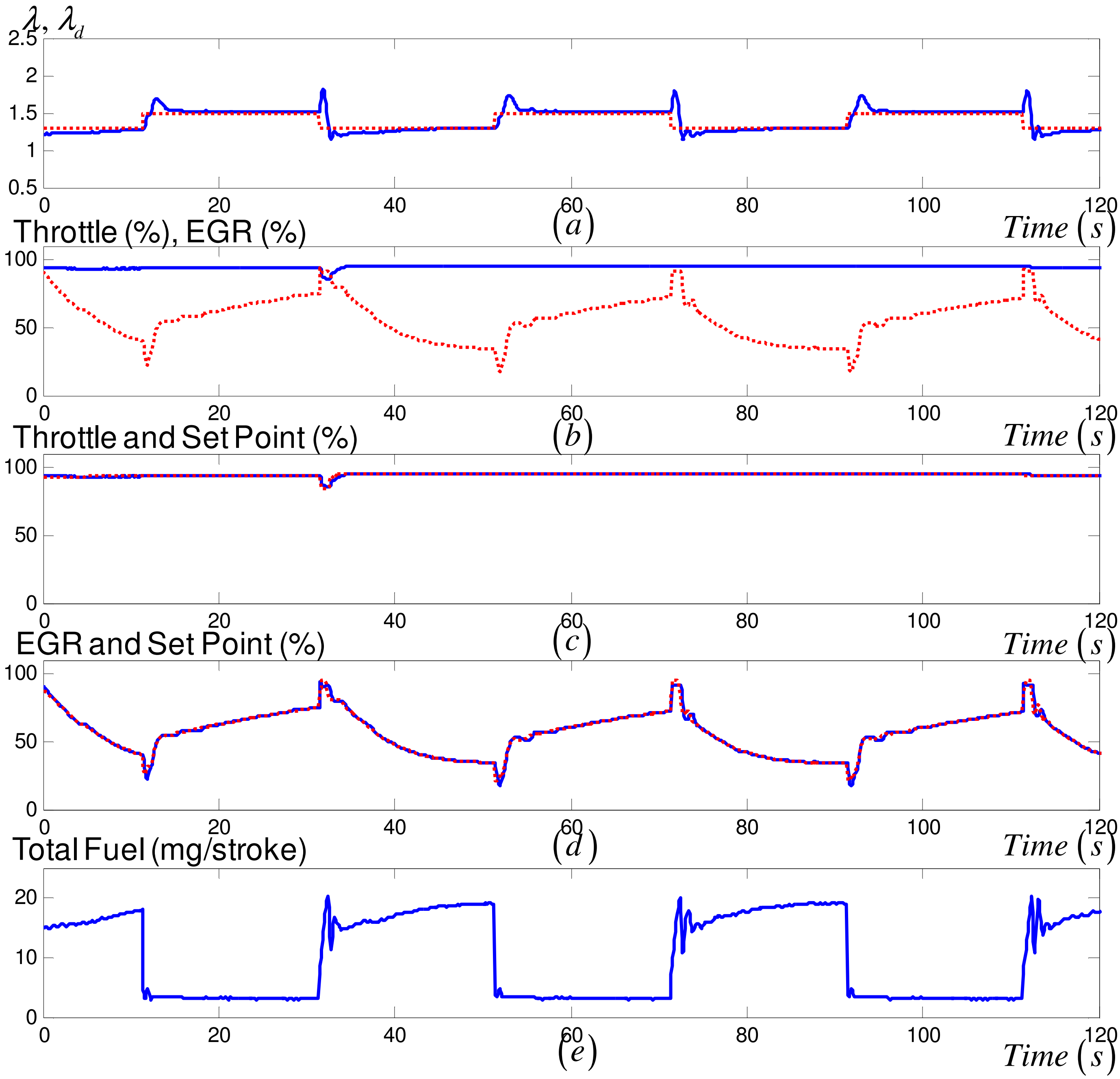


Figure 10: Set point changes test on an engine test bed using algorithm in Figure 6. (a) Actual lambda (solid line) and desired lambda (dash line.) (b) Throttle opening percentage (solid line) and EGR valve opening percentage (dash line.) (c) Throttle opening percentage (solid line) and its set point (dash line.) (d) EGR valve opening percentage (solid line) and its set point (dash line.) (e) Total fuel.

Figure 10 contains results of implementing the algorithm in Figure 6, where the tracking error affects the references of throttle and EGR valve and the total fuel. We can see that, as a result of adjusting the total fuel, the measured air/fuel ratio has noticeably lower overshoot and undershoot. This is because the fuel path has faster dynamic than the air path, therefore adjusting the total fuel improves transient behavior greatly. The total fuel in Figure 10(e) is much more active than those of Figure 8 and Figure 9.

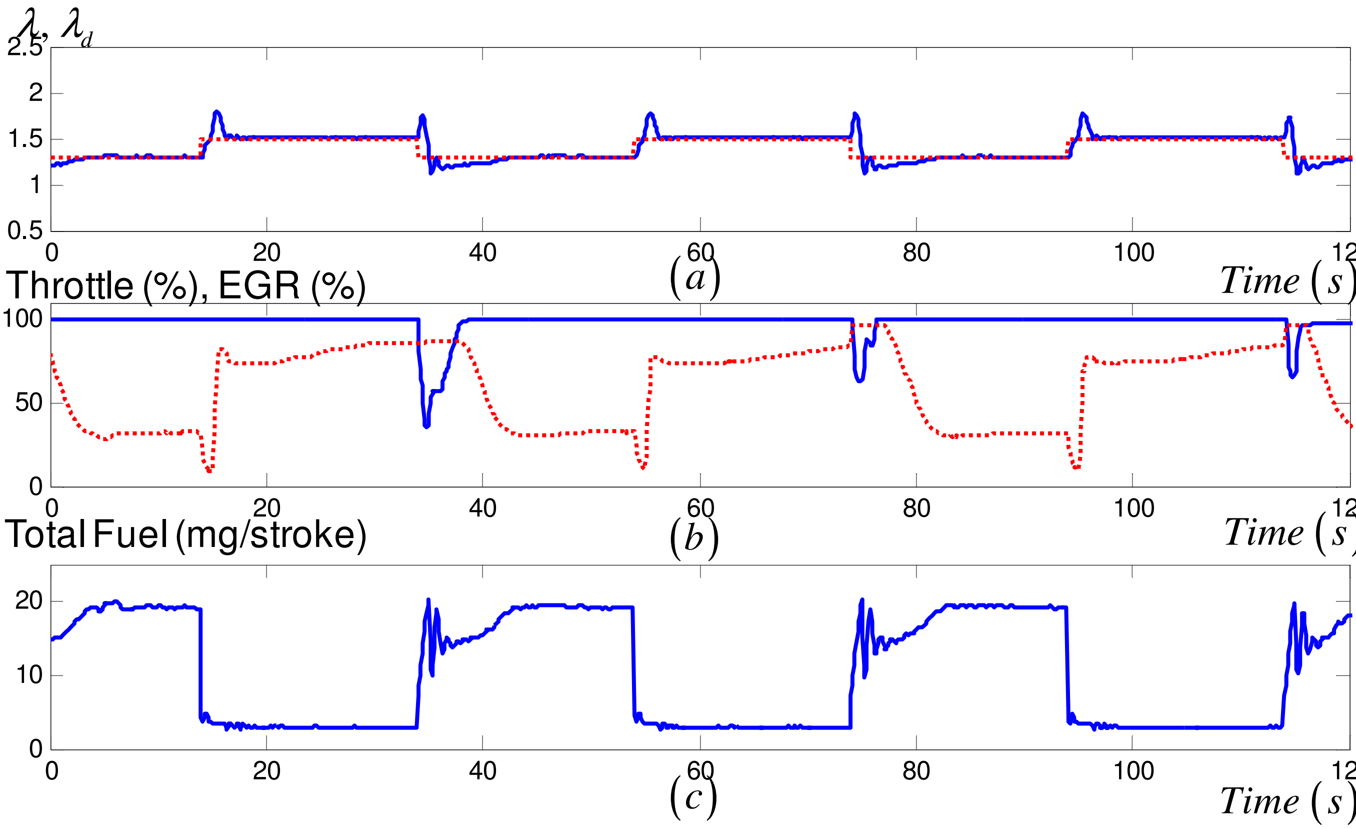


Figure 11: Set point changes test on an engine test bed using algorithm in Figure 7. (a) Actual lambda (solid line) and desired lambda (dash line.) (b) Throttle opening percentage (solid line) and EGR valve opening percentage (dash line.) (c) Total fuel.

Figure 11 contains the results of implementing the algorithm in Figure 7, where the tracking error affects the PWM duty cycle and the total fuel. The results in Figure 11 are comparable to those in Figure 10. We can see a more active total fuel movement in Figure 11(c) as a result of adjusting the PWM duty cycle directly.

The pick-up truck was commanded to follow the new European driving cycle (NEDC.) The whole cycle comprises four urban cycles, each of about 200 seconds, and a sub-urban cycle of about 500 seconds.

In following the NEDC, Figure 12 shows the throttle opening percentage versus the EGR valve opening percentage for four cases. Figure 12(a) is when no algorithm was implemented. Figure 12(b), (c), and (d) are when the algorithms in Figure 4 to Figure 6 were implemented, respectively. In Figure 12(a), both throttle and EGR valve were not at their optimum values since no switch-and-hold logic was implemented. This indicates higher pumping loss. In Figure 12(b), (c), and (d), the throttle and the EGR valve were both operated at their optimum values as expected. It should be noted that since our initial throttle and EGR valve openings were set at fully opened (100%) or at the top-right corner. According to the switch-and-hold algorithm, the throttle and EGR valve positions will never leave their top horizontal line and right vertical line. Notice also that some of the throttle openings in Figure 12(b) were lower than the lower bound, which is a disadvantage mentioned earlier of the algorithm in Figure 4. The fully closed throttle resulted in high emissions and should be avoided.

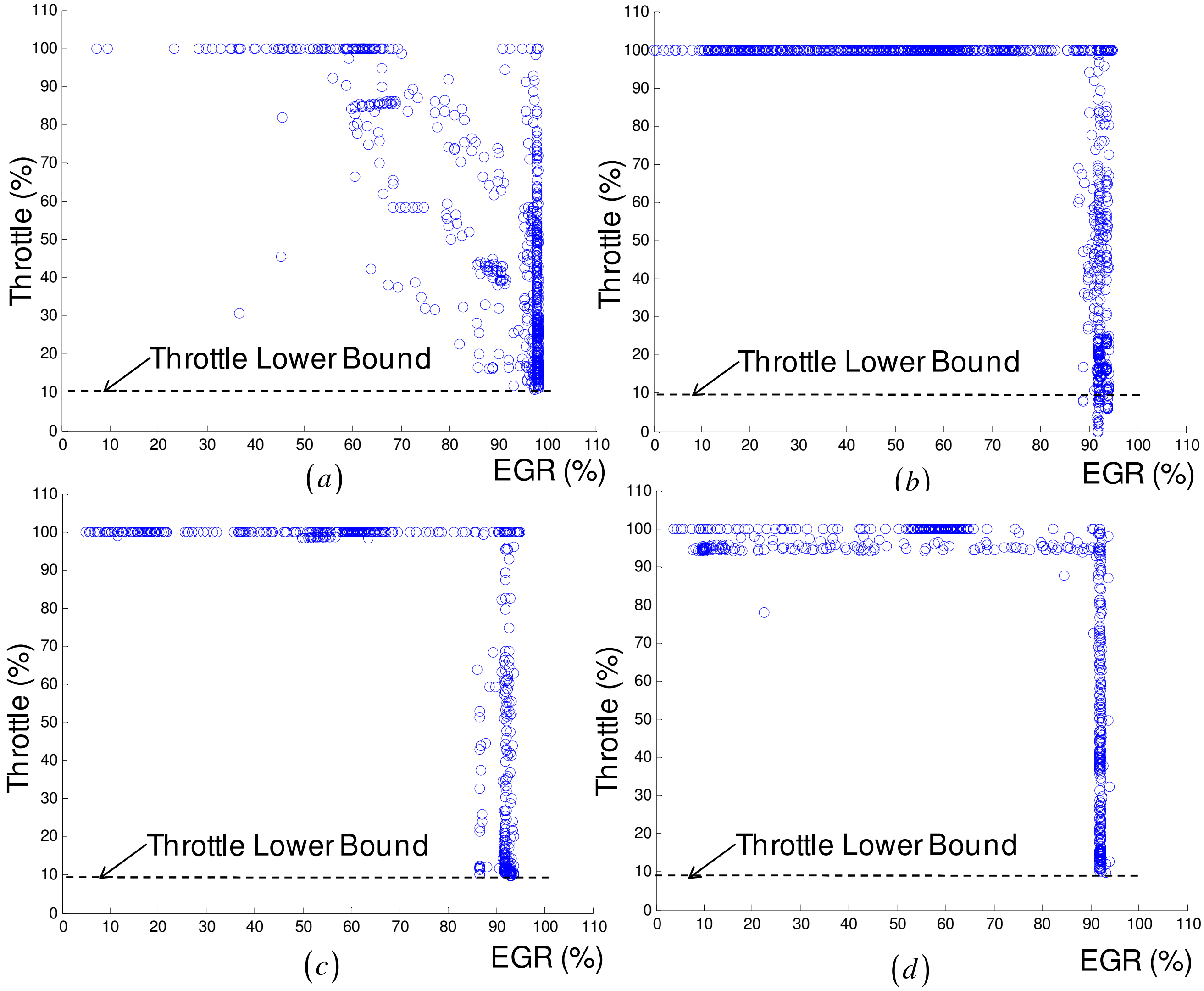


Figure 12: Movements of the throttle and EGR valve recorded from a pick-up truck following the new European driving cycle. (a) Without using any algorithm. (b) Using algorithm in Figure 4. (c) Using algorithm in Figure 5. (d) Using algorithm in Figure 6.

Figure 13 contains the tracking results from following the NEDC of the pick-up truck using the algorithm in Figure 6. Figure 13(a) shows the plots of the measured air/fuel ratio $\lambda$ (in solid line) and the desired air-fuel ratio $\lambda_d$ (in dash line.) Both are plotted versus time. Since similar tracking results were obtained for all four urban cycles, for clarity of presentation, only the results of the fourth urban cycle and the sub-urban cycle are presented. Figure 13(b) shows the plots of the throttle opening percentage (in solid line) and the EGR valve opening percentage (in dash line) versus time. Figure 13(c) shows the total fuel in mg/stroke.

In Figure 13(a), there are some intervals that the measured air-fuel ratio does not follow the desired air-fuel ratio closely, for example, during 600 to 620, 670 to 720, and 1050 to 1100 seconds. This is because, during these intervals, the engine mode was temporarily switched to use only diesel fuel for low load and the air-fuel ratio was temporarily not regulated. The measured air-fuel ratio was able to follow the desired air-fuel ratio closely with the exceptions of some points, for example, at around 820, 850, and 940 seconds, where both actuators reached their physical limits. The throttle opening is always above the lower bound.

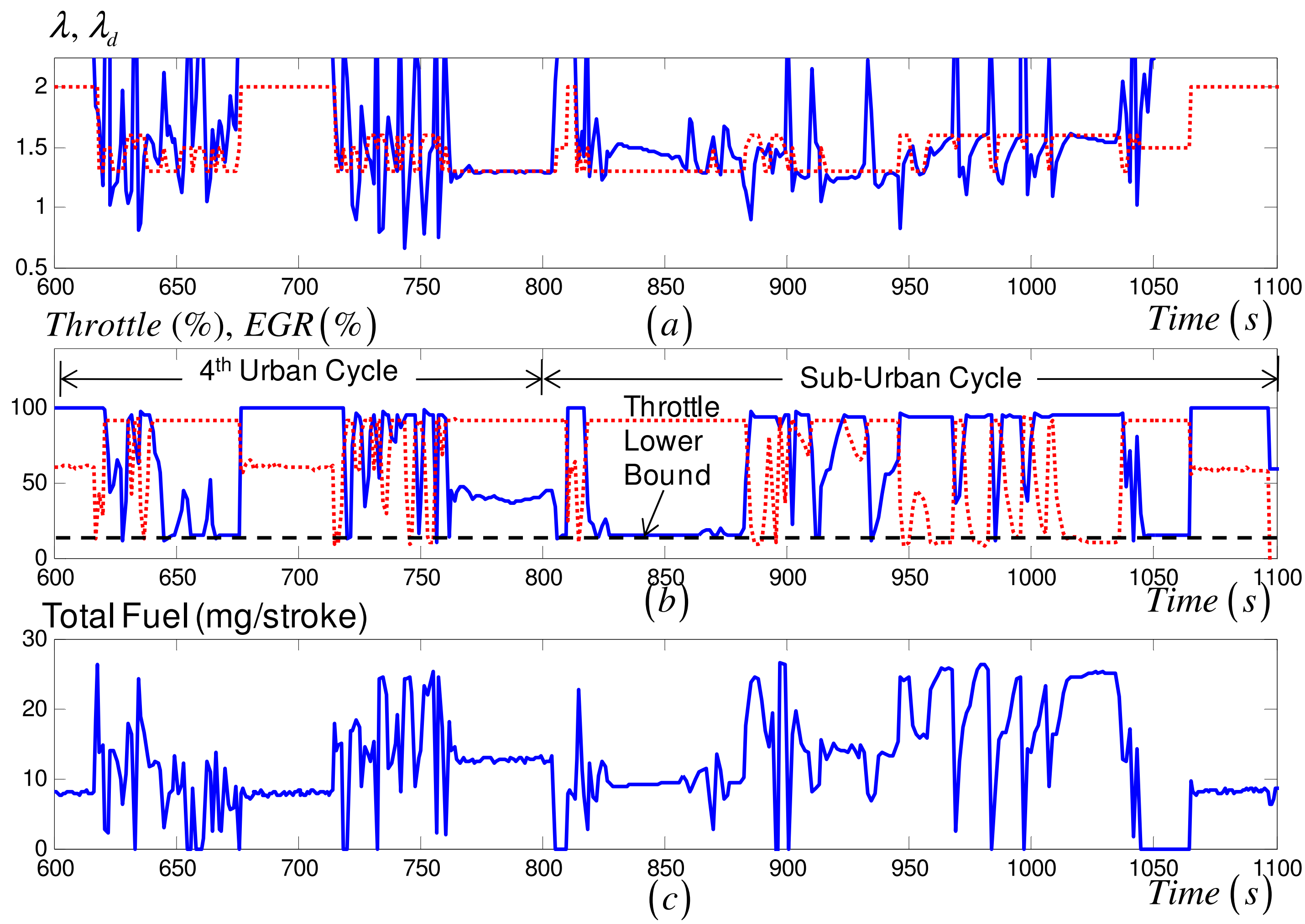


Figure 13: Fourth urban cycle and sub-urban cycle in an NEDC test on a pick-up truck, using the algorithm in Figure 6. (a) Actual lambda (solid line) and desired lambda (dash line.) (b) Throttle opening percentage (solid line) and EGR valve opening percentage (dash line.) (c) Total Fuel.

## CONCLUSIONS

Air/fuel ratio control in diesel-dual-fuel engine, by actuating throttle and EGR valve, has been presented in this paper. Several novel ideas have been presented. First, a switch-and-hold algorithm breaks multivariable problem into two single variable problems, which opens a way to any single-variable advanced control algorithms to be used with either throttle or EGR valve, one at a time. The switch-and-hold algorithm is also designed to minimize the pumping loss by opening the throttle as wide as possible. Second, a modification to the control algorithm was performed to be able to put a lower bound on the throttle and EGR valve openings, which prevent them from being fully closed, avoiding high emission. Third, a modification by adding control of the fuel path by changing the total fuel helps achieve better transient performance.

Further researches can be performed in computing the air/fuel ratio. In our work, we computed the air/fuel ratio from an MAF sensor, placed before throttle. Since the actual air/fuel ratio inside the cylinder is the one really affects the combustion behavior, an observer to estimate the amount of air inside the cylinder should be used. The air/fuel ratio can then be recomputed using the amount of air inside the cylinder.

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