Combustion Control Research – University of Alberta

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Motivation

The automotive industry has been increasingly scrutinized to produce cleaner vehicles by governmental agencies. In 2012, the US Environmental Protection Agency (EPA) and the Department of Transportation's National Highway Traffic Safety Administration (NHTSA) issued regulations to reduce greenhouse gas (GHG) emissions and improve fuel economy. Vehicles produced between 2017 to 2025 are required to adhere to this new regulation [1]. Fast and reliable emission measurement is needed to improve the efficiency of internal combustion engines and meet the future emission standards.

Homogeneous Charge Compression Ignition (HCCI) is a promising Low Temperature Combustion (LTC) method which reduces peak combustion temperature thus reducing NOx emissions compared to spark ignition engines. The autoignition process is also favorable to supporting various fuel types including biofuels. HCCI ignition timing is not directly controlled and is therefore highly dependent on in-cylinder state including pressure, temperature and fuel mass.

To reduce the overall engine emissions it is important to have real-time emission readings. Therefore, the development of cost effective portable sensors is desired. These sensors are required for controller input to be able to measure real-world engine exhaust components and adjust the combustion parameters accordingly.

International Partnership

The internal combustion laboratory at the university works closely with the Institute for Combustion Engines at RWTH Aachen University in Aachen, Germany. This ongoing collaboration allows for the transfer of students between universities working on joint projects in the areas of in-cycle control, bio-fuels, and advanced combustion methods such as HCCI.

vka Institute for Combustion Engines
RWTH AACHEN UNIVERSITY

cmp Mechatronic Systems for Combustion Engines
RWTH AACHEN UNIVERSITY

In-Cycle Control

In-cycle control is when the controller action takes place within the same engine cycle. This controller interaction can be valve timing changes, direct water injection, fuel injection or supporting spark as seen in Figure XXXX. The amount of time is very limited when we want the control action to begin within a single cycle.

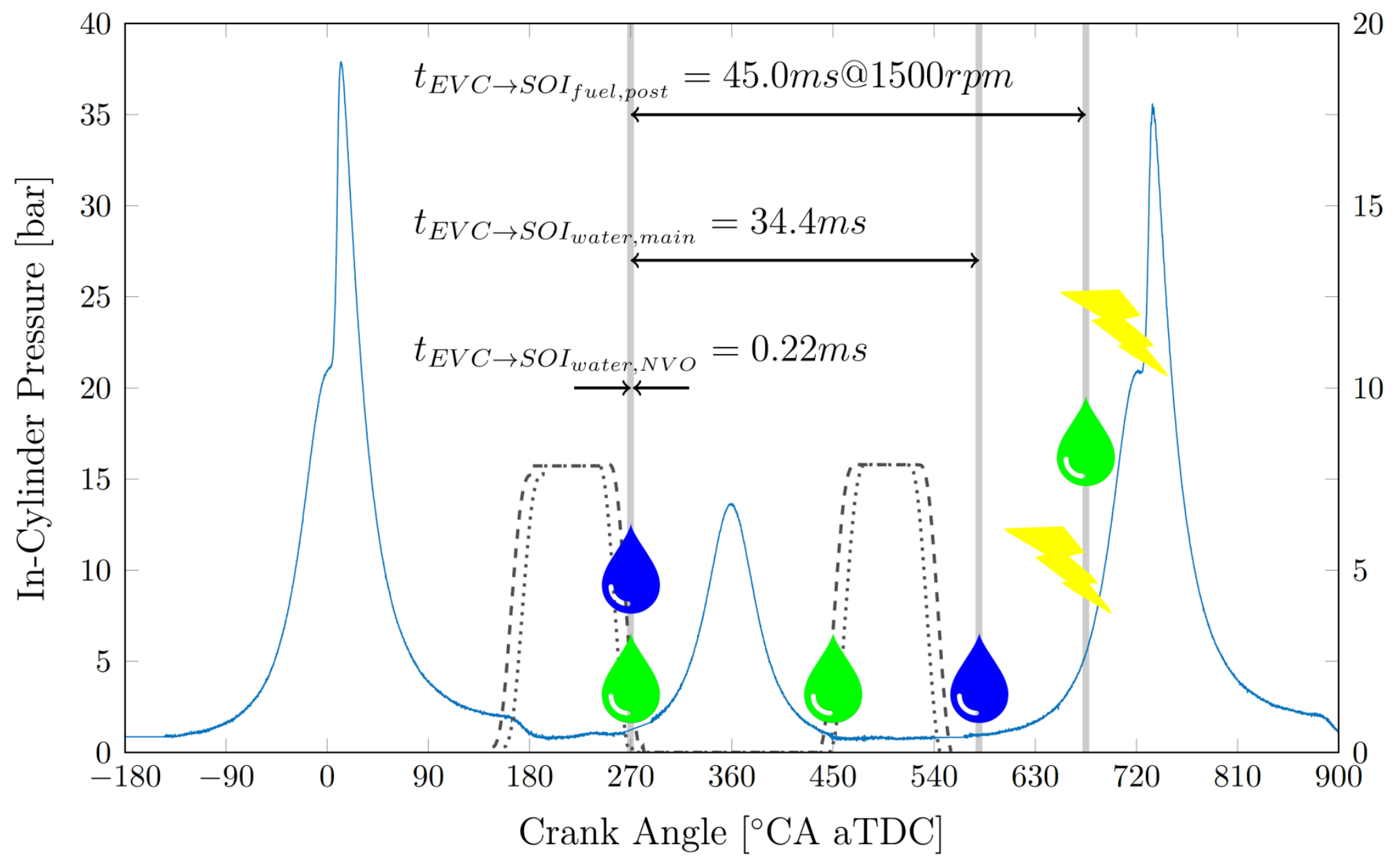

Figure 6 –In-Cycle control interaction options

Using an FPGA based calculation of the cylinder state it is possible to calculate the amount of fuel at every instant in the engine cycle. Using the FPGA this calculation take place in 3.53μs. Then by relating this residual fuel mass to the combustion phasing of the cycle a water injection controller can be implemented to regulate ignition timing.

The proposed controller prevents early rapid combustion cycles by using direct water injection to cool the cylinder charge and counter any additional thermal energy from any residual fuel that is transferred between cycles. Taking the residual fuel amount at exhaust valve closing (EVC) and wanting water injection to begin early in the negative valve overlap (NVO) period significantly limits the calculation time to the shortest possible control action presented in Figure XXXX.

By cooling the trapped cylinder mass the upcoming combustion phasing can be delayed to the desired setpoint. The goal of the proposed controller is the improvement of the combustion stability as shown by a reduction in the standard deviation of combustion phasing and indicated mean effective pressure.

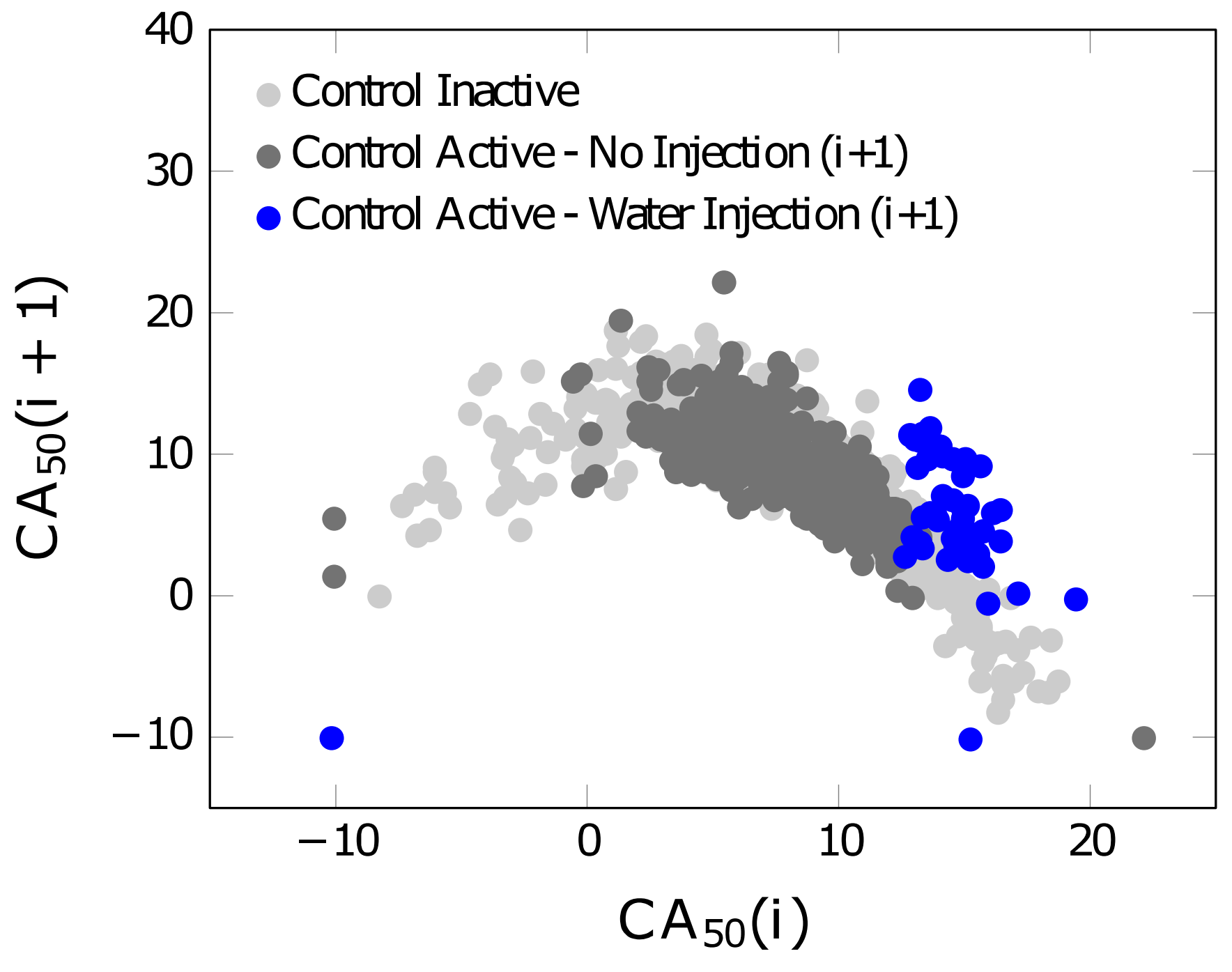

Figure 2 – CA50 return map showing the improvement in combustion stability at NVO = 185 CA, IMEP = 2.4 bar, SOI = 270 CA aTDC.

Emission Sensors

Solid electrolyte emission sensors are cheaper and faster than stationary emission measurement systems. In addition to their fast response, these sensors are portable which makes them ideal for real-time emission measurement and engine closed loop control. A schematic view and a photo of a solid electrolyte (amperometric) NOx sensor are shown in Figure 6 and Figure 7, respectively.

Experimental and numerical studies are being done in our research group, in order to improve the accuracy and reliability of solid electrolyte emission sensors.

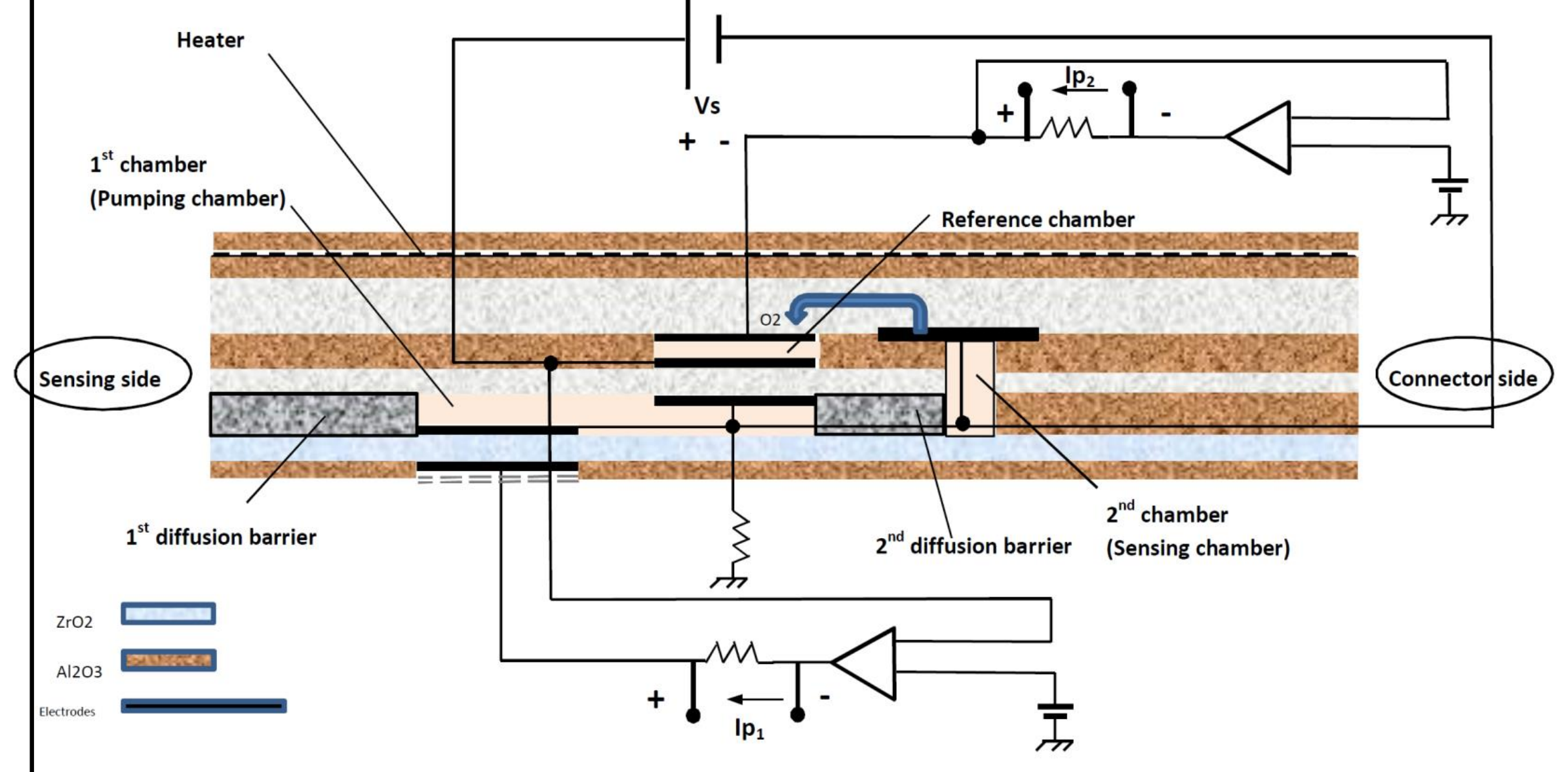

Figure 6 – Schematic view of a NOx sensor

Figure 7 – NOx sensor and the sensor control unit

To test the developed emission sensors a gas calibration bench has been designed and built. This experimental setup makes it possible to provide known quantities of various emissions gasses to the sensor. This experimental setup also allows for the temperature and humidity of the exhaust components to be precisely controlled. The schematic view of the test rig can be seen in Figure XXXX.

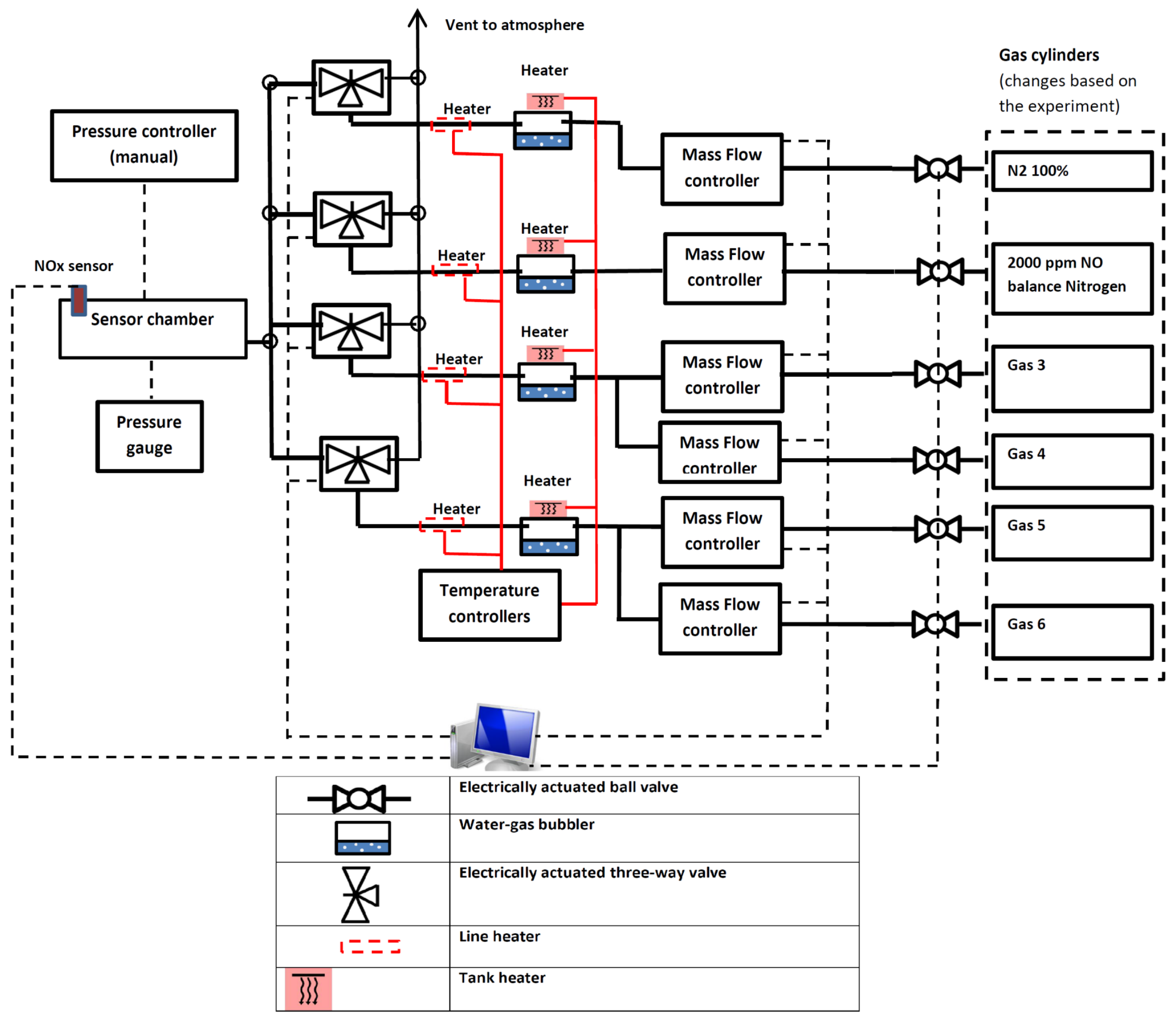

Figure 8 – Emission sensor calibration test setup

Advanced Engine Control

To control HCCI combustion it is necessary to create a model that captures the complex combustion process. However, it is also important that this model be as simple as possible to be able to apply controllers in real-time. These simplfed models for control are called control oriented model (COM) and one can be seen in Figure 9.

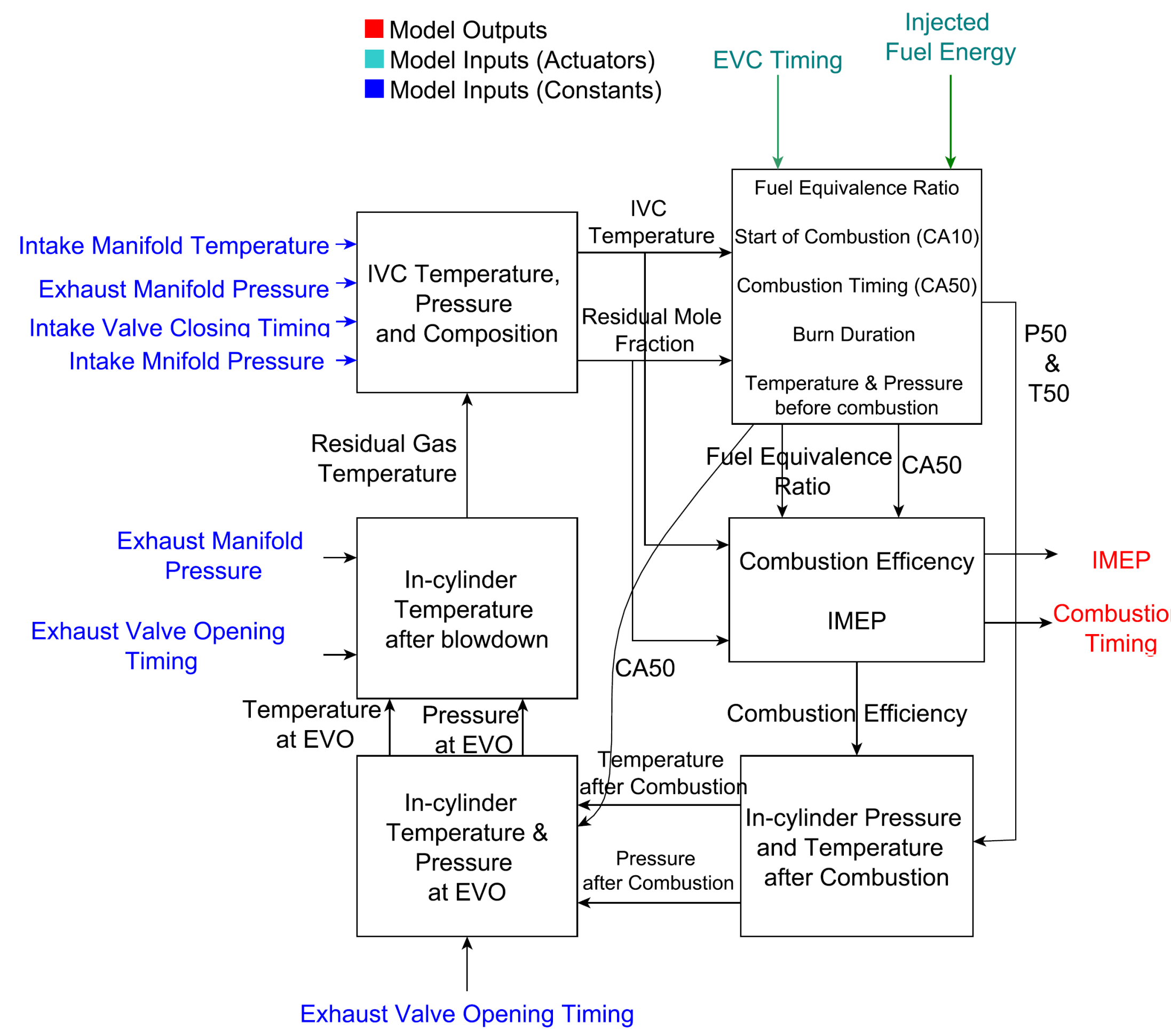

Figure 9 – Nonlinear Control Oriented Model Structure

Using this COM then more advanced control methods can be applied. One example is an Integral Discrete-time sliding Mode control (IDSMC) and is shown schematically in Figure 10. This control strategy is useful for HCCI control because IDSMC performs well in rejecting fuel equivalence ratio and intake temperature disturbances compared to conventional controllers. IDSMC also shows better tracking accuracy compared to the conventional controller in the presence of state disturbance and input uncertainties.

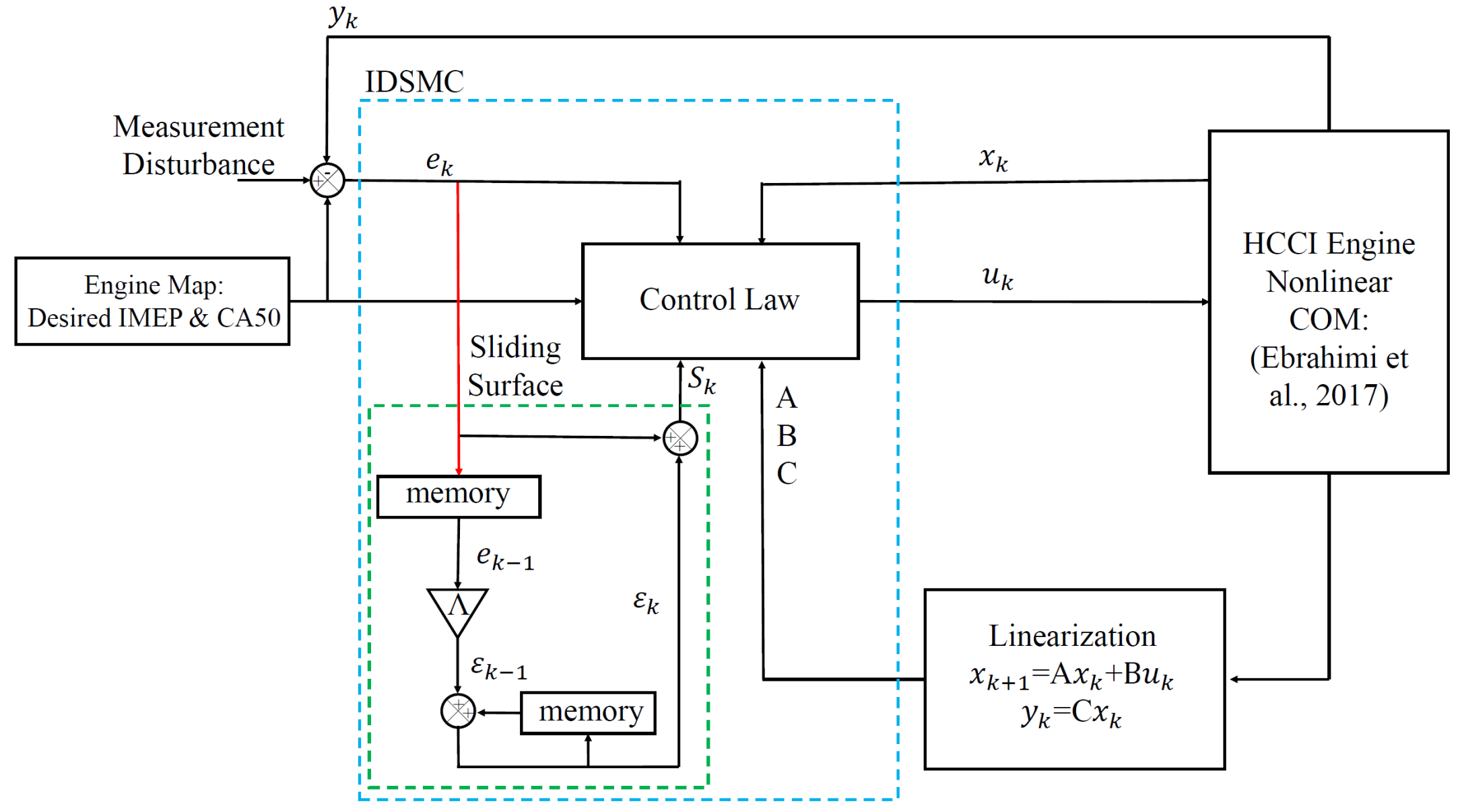

Figure 10 – The Block diagram of the IDSMC controller

References

[1] EPA and NHTSA Set Standards to Reduce Greenhouse Gases and Improve Fuel Economy for Model Years 2017-2025 Cars and Light Trucks, U.S. EPA EPA-420-F-051, Aug 2012.

[2] J. E. Dec. Advanced compression-ignition engines understanding the in-cylinder processes. Proceedings of the Combustion Institute, 32(2):2727 – 2742, 2009. ISSN 1540-7489