RAPID CONTROL PROTOTYPING SYSTEM dSpace USED FOR CONTROL OF COMBUSTION ENGINE PROCESSES

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Abstract

The aim of this paper is to present fitness of Rapid Control Prototyping system (RCP system) dSpace in the development of the control algorithms for combustion engine processes. RCP system dSpace is fully programable from Simulink. As an application interface for handling of hardware features exists a set of Simulink blocks called Real Time Interface (RTI) and a set of functions (RTlib) which can be used in C mex S-functions. For handling of real time application running on dSpace system was used ControlDesk software and ConfigurationDesk for some settings relevant to RapidPro modules. The results of Air/Fuel ratio predictive control will be also presented.

1 Introduction

Before advent of the Electronic Control Unit (ECU) on the field of Combustion Engine Control the two main control loops (for ignition and Air/Fuel ratio control) were realized continuously. Continuously working systems designated for control of these tasks didn't achieve sufficient precision, were difficult to adjust, unreliable and due to solutions of these inadequacies became costly. Nowadays, electronic "digital" control units (ECUs) are used. Such ECUs are systems where the heart of them is microcomputer which serve for data acquisition, computing, communications with other systems and driving of the actuator's power stages. In this book [3] the basic concept is presented. Additionally these systems must performs different diagnostic services. Design and building of such ECU is not a simple problem. In the phase of a control algorithm implementation, the register level programming for target platform (a specific microcomputer used in ECU) is required. For these reasons, development and testing of designed control algorithms became very difficult. For the reduction of difficulties Rapid Control Prototyping systems (RCP systems) has been developed over time. These RCP system are systems, which are usually hardware modular and have a good software support. Hardware modularity is a feature enabling to compose system, which meet the requirements. At least one module has to be a microprocessor module. This module provides more capabilities (computational power and larger memory) and so it is possible to test advanced control algorithms without the need for optimized code. Good software support means, that the producer of such modular RCP systems supplies the libraries and documentation. These libraries serves as a application interface for handling of devices's features (for example handling of interrupts, reading of the values from analog to digital conversions etc.). In addition, the host service code is running on the RCP system. This host service ensures the data exchange between the real-time hardware and a host computer. The next essential feature of RCP systems is, that they are software configurable. In one word, using of Rapid Control Prototyping systems in development enables to deal with programming of algorithms which are objects of investigation without the requirements to deal with problems like design and realization of hardware and handling of its features by low level programming. In the next chapters of this paper, will be explained the use of dSpace Rapid Prototyping system in a problem of combustion engine processes control.

2 Control of Spark Ignition Combustion Engine

Combustion Engine is naturally discrete-event system which works periodically, each cycle performs the same acts. In the case of four stroke combustion engine this cycle has a period of

720 ° of crank-angle. During this cycle each piston performs each of four strokes. Rapid Control Prototyping system (RCP system) dSpace with configuration as is possible to see at Figure 1 enables to handle every of the events in a crank-angle or time domain.
In this paper will be presented results of A/F ratio predictive control based on web of linear models. This approach described in PhD thesis [9] is one of the many published, based on computation in time domain. For this approach was crucial to obtain two linear models (for fuel and air path) in each operational point (revolutions $\times$ throttle position) of the web. Second typical approaches called Event Based described in [5], [4], [6] and [7] was used earlier. One of the Event Based A/F ratio control approach (based only on feedforward A/F ratio controller) was used, with goal to get engine to steady state for possibility of making the identification experiments and so build the mentioned web of local linear models.

2.1 RCP System dSpace Used for Control of Combustion Engine Processes

As was mentioned above, in Figure 1 is showed the scenario in which we use RCP system. The main real-time program made in Simulink is running on real-time proccesor included in DS1005 processor board. The part of RapidPro is processing of the signals from given sensors (providing them to Master dSpace system), generating of signals for driving of given actuators (look at Table 2) and generating of interrupts requests. For example, computed inputs (by given algorithms running on DS1005), injection start angle, injection time, ignition start angle and stop angle are sent (updating with new values) to RapidPro and then RapidPro generates so defined impulses to actuators. RapidPro can generate angle based interrupts which enables to trigger tasks in specific crank angles (for execution of interrupt service routines by real-time processor). The values of crank angle are necessary to be sent to RapidPro system too. For example these angle based interrupts can be used for capturing of given computed (by control algorithm running on DS1005) input and for consecutive update to RapidPro by invoking of software or time delayed interrupt request. Signals which are processed by RapidPro, for example crank angle, revolutions, temperature of lambda probe (heater element), lambda (temperature and lambda measurement are sampled by RapidPro internaly) is possible to read by sample time of any Timer Task provided by DS1005 processor board. In this sense it is also possible to read values of signals connected and processed by I/O board DS2202 (look at Table 1). Reading of these signals is possible in crank angle domain too.

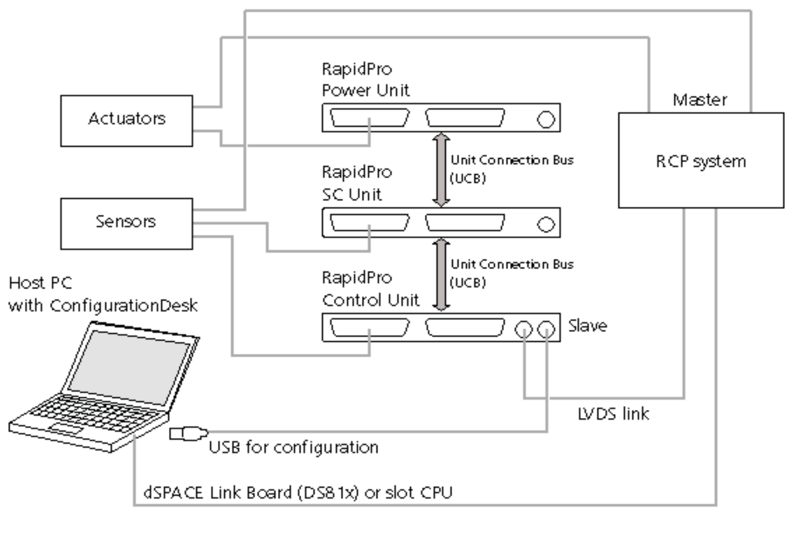

Figure 1: RCP system configuration

The user has to design this sampling with regard to computational power, with the aim of achieving task scheduling without overrun situations and without overloading of RapidPro. Code generated by Real Time Workshop for target platform rti1005 has a measurement of turnaround time of each task in your model. For detailed information what the turnaround time of any task includes and for detailed specification of the hardware and software support see dSpace documentation [1].

In the next two tables are listed modules used for our application. There is a short description of its exploitabilities at second columns.

type	short description
DS1005 module	processor board, based on real-time processor PowerPC 750 is a main processing unit and host interface
DS2202 module	I/O board, analog inputs and outputs for: control of electronic throttle position, MAF sensor, MAP sensor, oil and cooling water temperatures, braking torque and battery voltage
DS4121 module	interface board, makes communication between Master and Slave systems

Table 1: List of dSpace modules

type	short description
MC-MPC565 1/1 module (DS1602)	microcontroller module, based on MPC565 microcontroller
SC-CCDI 6/1 module (DS1637)	for connecting of crankshaft and camshaft signals
SC-EGOS 2/1 module (DS1634)	for connecting of exhaust gas oxygen sensor (lambda probe LSU4.9 Bosch)
SC-KNOCK 4/1 module (DS1635)	for connecting of knock sensor
PS-LSD 6/1 (DS1662)	low side driver, for driving of lambda probe heater element and ignition modules
2 x PS-DINJ 2/1 module (DS1664)	for driving of electromagnetic injection valves
COM-USB-CI 1/1 module (DS1609)	for configuration from Host PC
COM-LVDS 1/1 module (DS1606)	module for communication with Master dSpace system

Table 2: List of RapidPro modules (RapidPro as a Slave system)

In this Table 3 are listed specifications about the used combustion engine. The specifications about used sensors and actuators and control algorithms used for specific purpose (lambda probe element heating, electronic throttle position control, control for constant revolutions by loading of engine by eddy current brake etc.) can be found in papers [2] and [8].

type	Škoda Fabia 1.4 16V
code	AUA
cubature	$1390cm^3$
number of cylinders	4
number of inlet valves	16
borehole × throw	76.5 × 75.6 mm
compression ratio	10.5
power	55kW (75HP) by 5000rpm
torque	126Nm by 3800rpm
jetting	multi point, 1 injection valve / cylinder
ignition	electronic
fuel	Natural 95

Table 3: Combustion engine type

2.2 Computation of Fuel Mass, Preignitions and Driving of the Actuators in Crank Angle Domain (Event Based)

The first problem which the user must solve is obtaining of information about shapes of wheel on the crankshaft, on the camshaft and their relation to position of pistons. For this purpose the measurement has been done. The next Figure 2 represent setup of this measurement. Data Acquisition Toolbox with NI6008 was used for measuring of the mentioned wheel's shapes. Furthermore the signal from hall sensor was measured, which scanned the transfer of the magnet under it. This magnet was glued in such position, that measured impulse carried information about TDC position.

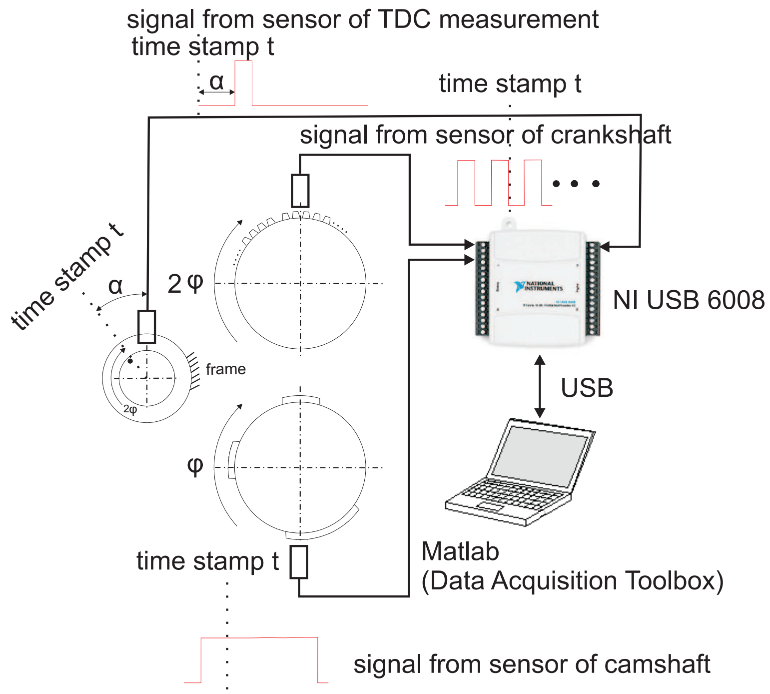

Figure 2: Measuring system

The result gave the possibilities to configure the necessary setup for crankshaft angle and speed measurement together with relation to piston's positions. This can be seen in Figure 3 and in the next list.

Shape of crankshaft wheel:

- has 60 teeth.
- has 1 gap.
- 2 missing teeth per gap.

Shape of camshaft wheel:

- has 3 markers.
- coordinates of rising edges are [36 ° 258 ° 576 °].
- coordinates of falling edges are [102 ° 456 ° 636 °].

With this knowledge the basic feedforward A/F ratio and ignition controls can be explained. In this case we will only talk in detail about task scheduling, which are needed for explaining of feedforward A/F ratio and ignition controls. We will not present achieved quality of these control strategies, because it served only for achievement of desired engine's steady state and after it the A/F ratio controller was turned off for making identification experiments. This feedforward A/F ratio controller meets the requirements on the quality of control in steady state.

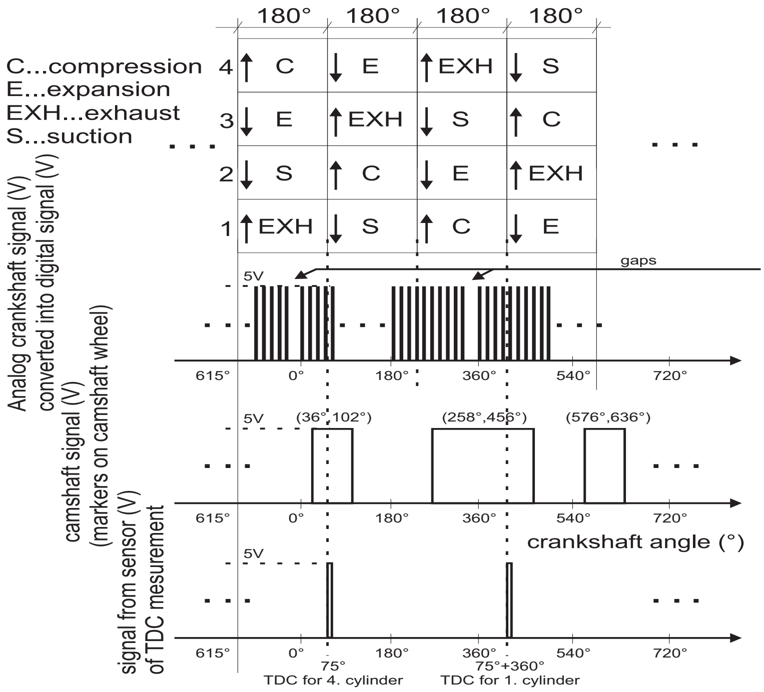

Figure 3: RCP system configuration

In the next Figure 5 are the crank angle axis and markers of the moments in which the actions are triggered. Before the explaining of this timing, is the Table 4 which contains the list of tasks arranged by the priority.

First task with sample time 0.0001s serves for sampling of time and MAF signal. Such sampled time and MAF signal is used for computation of air mass sucked to combustion chamber in time of one suction stroke (numerical integration) (by 6000rpm of revolutions the angle of 3.6° takes 0.0001s). This information about air mass sucked per one suction stroke is used for computation of needed fuel mass for achieving of desired fuel mixture (A/F ratio). Consequently this actual fuel mass is recomputed on injection time, from characteristics of injection valve with regard to the fact that controller of fuel pressure is mounted (so a constant difference of pressure is achieved). Then it is captured and updated for driving of the cylinder which is in the actual suction stroke. It is because the injection is started at beginning of compression stroke for the given cylinder. Computation of preignition is performed at the start of each cycle (at crank angle 0°). This datum is then updated separately for all of cylinder in order which is present in Figure 5. In this Figure 5 are showed all moments in which the selected tasks are performed.

priority	type	short description
1	TimerTask1, 0.0001	some measurements, look at the text below
2	Angle based interrupt, 3.6° periodically started from TDC	numerical integration of MAF signal
3	Angle based interrupt (master1), 180° periodically started from TDC	capture and reset of air mass
4	Software interrupt (slave1)	computation of fuel mass => computation of injection time
5	Angle based interrupt (master2), 165°	capture of injection time for 1. cylinder
6	Software interrupt (slave2)	update of injection time for 1. cylinder
from 7 to 12	Angle based interrupts for next cylinders in order 3,4,2	captures and updates of injection time
13	Angle based interrupt, 0°	computation of preignition
14	Angle based interrupt, 120°	update of preignition for 2. cylinder
from 15 to 17	Angle based interrupts for next cylinders in order 1,3,4	updates of preignition
18	TimerTask2, 0.0005	for reading of λ measurement
from 19 to where necessary	Others interrupts	for all sample times included in the given Simulink model

Table 4: List of the tasks

3 Results

At our institute, on engine work-bench with RCP system dSpace was a A/F ratio model predictive controller designed and tested, as is described in [10] and [9]. The result of this research is presented in this paper only for illustration and you can see it in Figure 4.

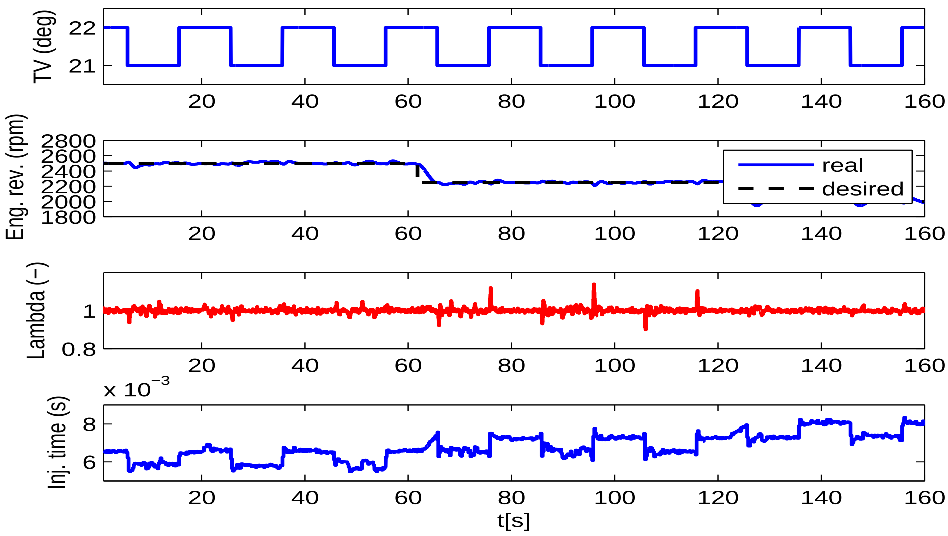

Figure 4: Behavior of control process

4 Acknowledgments

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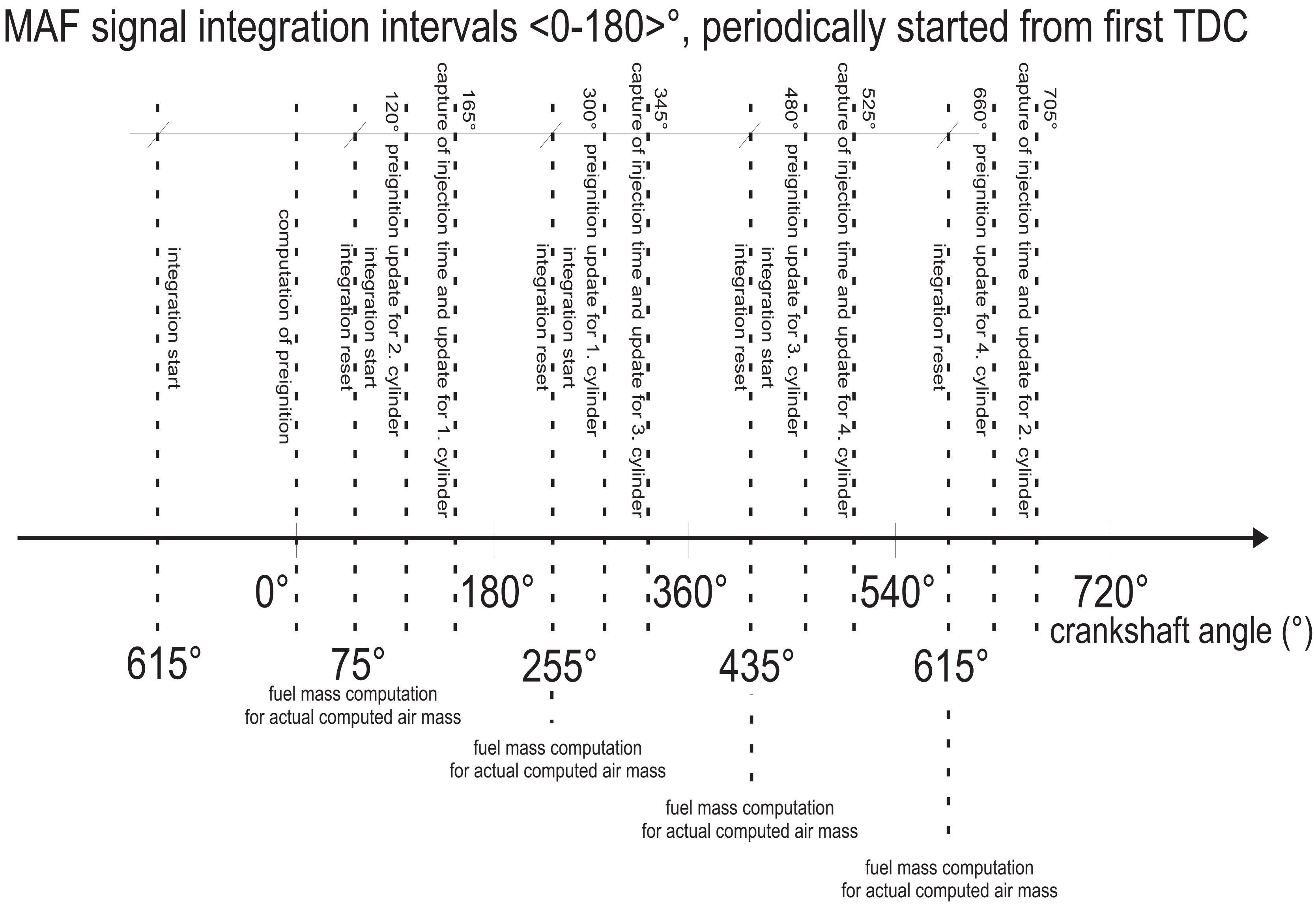

Figure 5: Timing of the main tasks