Distributed Parameter Systems Blockset for Simulink --- Third-Party MathWorks Product ---

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Abstract: In the paper, first fundamentals of the engineering approach to the control of distributed parameter systems will be indicated. Then the Distributed Parameter Systems Blockset for Simulink with Show, Demos and DPS Wizard – third-party MathWorks product will be presented. Some possibilities of this product are shown by control of complex shape 3D metal body heating - modeled by numerical structures of finite element method.

Keywords: Distributed parameter systems; lumped-input/distributed-output systems; time/space decomposition of dynamics and control synthesis; distributed parameter PID, algebraic, state space, robust control; web based control design environment; finite element method.

1 Introduction

Nowadays is paid considerable attention to the numerical dynamical analysis of diverse processes, machines, apparatuses,... as dynamical systems given over complex shape 3D definition domains. In general, such kind of systems are Distributed Parameter Systems (DPS). New software systems have been developed to treat these problems: ANSYS, FEMLAB, FLUENT, MODFLOW, STAR-CD, PAM-SYSTEM,... a new discipline emerges in this sphere of applications – computational science and engineering.

Now, attractive 3D animations "jumping" on computer screens is a great challenge for control community to control these processes...

The DPS Blockset is a blockset for use with MATLAB & Simulink for distributed parameter systems and their applications in modeling, control and design of dynamical systems given on complex 3D domains of definition.

The blockset features:

- Engineering methods for DPS modeling, control and design
- DPS models based on lumped-input/distributed-output systems, time/space analysis, synthesis and design tools
- Distributed parameter PID, algebraic, state space and robust control schemes
- DPS Wizard demonstrates in step-by-step operation distributed parameter control loops arrangement and setting procedures
- Suite of blocks and schemes for DPS control practically in any field of technical practice
- Interactive Control Service for support DPS control solutions via the internet

In the paper, first fundamentals of the engineering approach to the control of DPS will be presented: distributed-input/distributed-output systems (DDS), lumped-input/distributed-output systems (LDS), decomposition of dynamics of controlled systems to time and space components and decomposition of control synthesis to time and space tasks. Further, particular sections of web-based control design environment **Distributed Parameter Systems** will be described with accent on the Distributed Parameter Systems Blockset for Simulink – third-party MathWorks product from web site www.dpscontrol.sk .

2 DPS - DDS - LDS

In general, DPS are systems whose state or output variables, X(x,y,z,t)/Y(x,y,z,t) are distributed variables or fields of variables, where (x, y, z) is a vector in 3D. In control theory, these systems are frequently considered as systems whose dynamics is described by partial differential equations (PDE), Butkovskij (1965), Lions (1971), Wang (1964). In the input-output relation, PDE define distributed-input/distributed-output systems (DDS) between distributed input U(x,y,z,t) and distributed output variables Y(x,y,z,t) at initial and boundary conditions given, see Fig. 1.

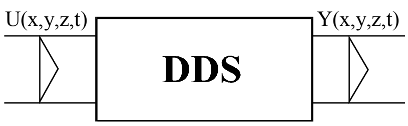

Fig. 1
Distributed-input/distributed-output system

Distributed parameter systems frequently are found in the engineering practice as LDS, see Fig. 2, having the common structure according to Fig. 3. Here, the DDS block is obtained as a special case of LDS one.

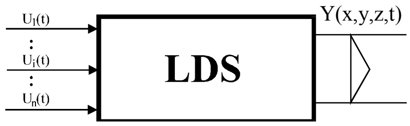

Fig. 2
Lumped-input/distributed-output system: $\{U_i(t)\}_{i=1,n}$ - lumped input variables, Y(x,y,z,t) - distributed output variable

Dynamics of LDS is decomposed to time and space components. In the time dependency, there are for example discrete transfer functions:

$$\{SH_i(\overline{x}_i, z)\}_{i=1,n} \tag{1}$$

between i-th input variable and corresponding partial distributed output variable at point $\overline{x}_i = (x_i, y_i, z_i)$.

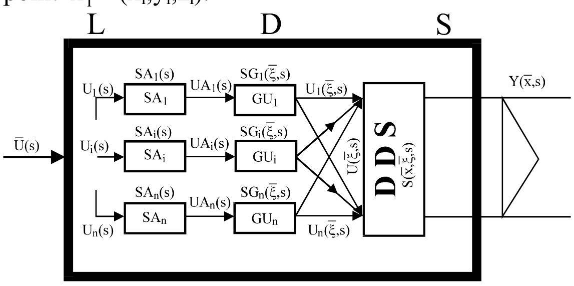

Fig. 3
Lumped-input/distributed-output system structure: $\{SA_i(s)\}_{i=1,n}$ - transfer functions of actuating gears of lumped variables $\{SA_i\}_{i=1,n}$; $\{SG_i(\overline{\xi}, s)\}_{i=1,n}$ - transfer functions of generators of distributed input variables $\{GU_i\}_{i=1,n}$; $S(\overline{x}, \overline{\xi}, s)$ - transfer function of distributed-input/distributed-output system; where $\overline{x}, \overline{\xi}$ - are vectors in 3D.

In the space dependency there are e. g. reduced transient step responses in steady-state:

$$\{HHR_i(\overline{x}, \infty)\}_{i=1,n} \tag{2}$$

3 Distributed Parameter Systems of Control

Decomposition of dynamics enables also to decompose the control synthesis to time and space control tasks in distributed parameter control loop, see Fig. 4.

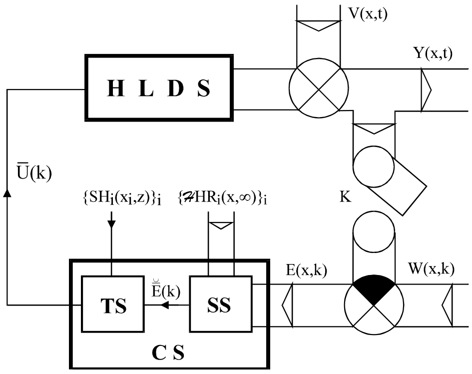

Fig. 4
Distributed parameter discrete feedback control loop at unit sampling period: HLDS - LDS with zero-order holds $\{H_i\}_i$ on the input, CS - control synthesis, TS - control synthesis in time domain, SS - control synthesis in space domain, K - time/space sampling, $Y(\bar{x},k)$ - distributed controlled variable, $W(\bar{x},k)$ - control variable, $V(\bar{x},t)$ - disturbance variable, $E(\bar{x},k)$ - distributed parameter control error

In the block SS, approximation of distributed control error $E(\bar{x},k)$, on the set of reduced steady-state distributed step responses $\{HHR_i(\bar{x},\infty)\}_i$, is solved. As the solution of approximation problem, lumped control error vector $\breve{\bar{E}}(k)$ enters into the block TS, where vector of control variables $\bar{U}(k)$ is generated. The controllers, $\{R_i(z)\}_i$, Fig. 5, are tuned in single-parameter control loops $\{SH_i(\bar{x}_i,z),R_i(z)\}_i$, according to single components of the time part of the controlled distributed parameter system dynamics $\{SH_i(\bar{x}_i,z)\}_{i=1,n}$, see Fig. 6.

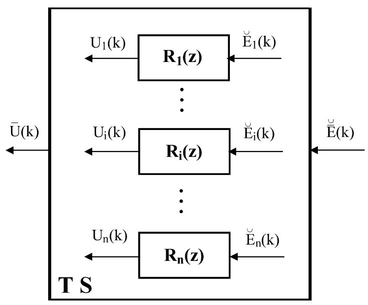

Fig. 5
Time synthesis block

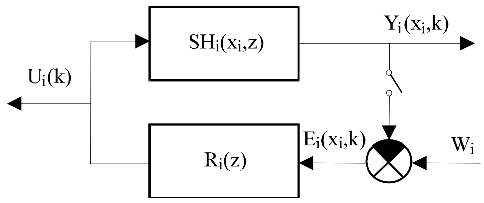

Fig. 6
i-th one-parameter control loop

On this principle, the distributed parameter control synthesis at PID, algebraic, state, robust as well as adaptive or intelligent control is decomposed into the time and space tasks, Hulkó (1998 - 2003).

4 Distributed Parameter Systems Blockset

The web-based control design environment: **Distributed Parameter Systems** on the web site www.dpscontrol.sk offers both, methodical and software support for education and solution of engineering tasks as well as possibilities of interactive formulation and solution of model tasks of distributed parameter systems control via the internet. It is arranged on www.dpscontrol.sk and includes: a full downloadable demo version of Distributed Parameter Systems Blockset for Simulink – third-party MathWorks product, web Service for support distributed parameter control solutions via internet, in frame of LDScontrol – Control of Dynamical Systems Given on Complex Definition Domains and internet version of the monograph Hulkó et. al. (1998).

The block **HLDS** models controlled distributed parameter systems as lumped-input/distributed-output systems with zero-order hold units. The **DPS Control Synthesis** provides feedback to distributed parameter controlled systems in control loops with blocks for **PID, algebraic, state space and robust** control. The block **DPS Input** generates distributed quantities which can be used as distributed control variables or distributed disturbances, etc. **DPS Display** presents distributed quantities with many options including export to AVI files. The block **DPS Space Synthesis** performs space synthesis as an approximation problem. The block **Tutorial** presents methodological framework for formulation and solution of distributed parameter systems of control. The block **Show** contains motivation examples: Control of temperature field of 3D metal body, Control of 3D beam of „smart" structure, Adaptive control of glass furnace and Groundwater remediation control. The block **Demos** contains examples oriented to methodology of modeling and control synthesis. The **DPS Wizard** in step-by-step operation, by means of five model examples on 1D-3D with default parameters, gives a guide for arrangement and setting distributed parameter control loops.

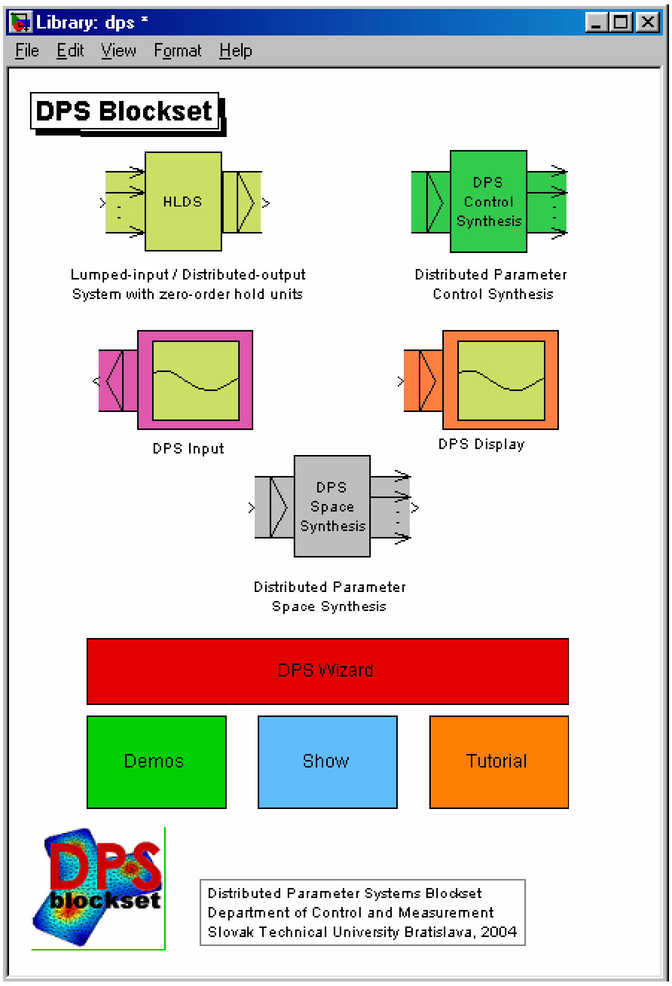

Fig. 7
DPS Blockset for MATLAB & Simulink

The block **Show** contains some motivation examples:

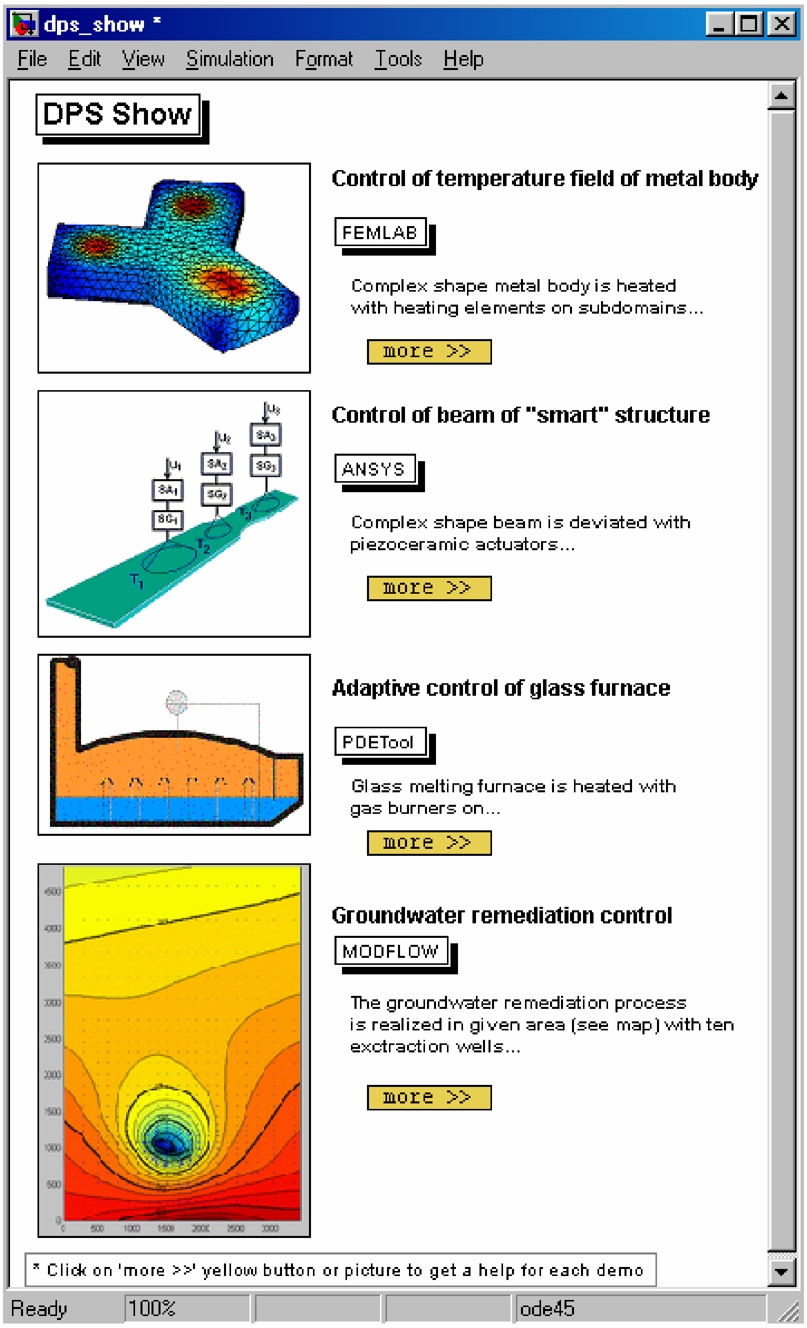

Fig. 8
Block Show of the DPS Blockset for MATLAB & Simulink

The block **Demos** contains examples oriented to methodology of modeling and control synthesis:

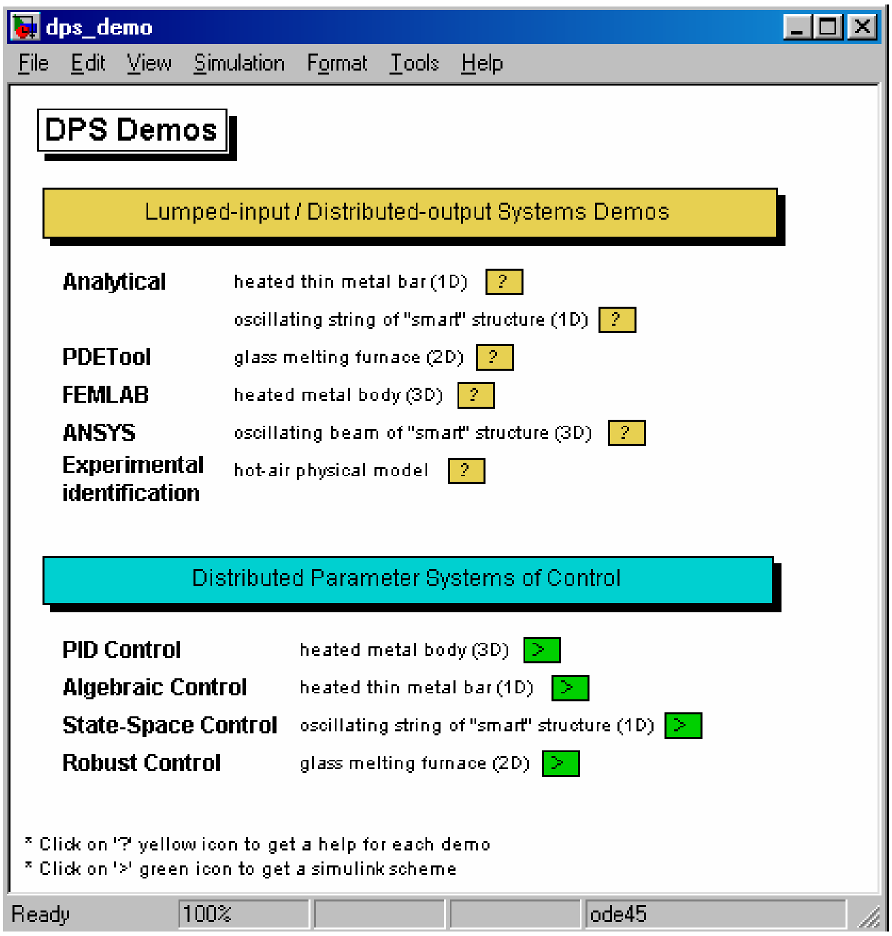

Fig. 9
Block Demos of the DPS Blockset for MATLAB & Simulink

The **DPS Wizard** in step-by-step operation, by means of five model examples on 1D-3D with default parameters, gives a guide for arrangement and setting distributed parameter control loops.

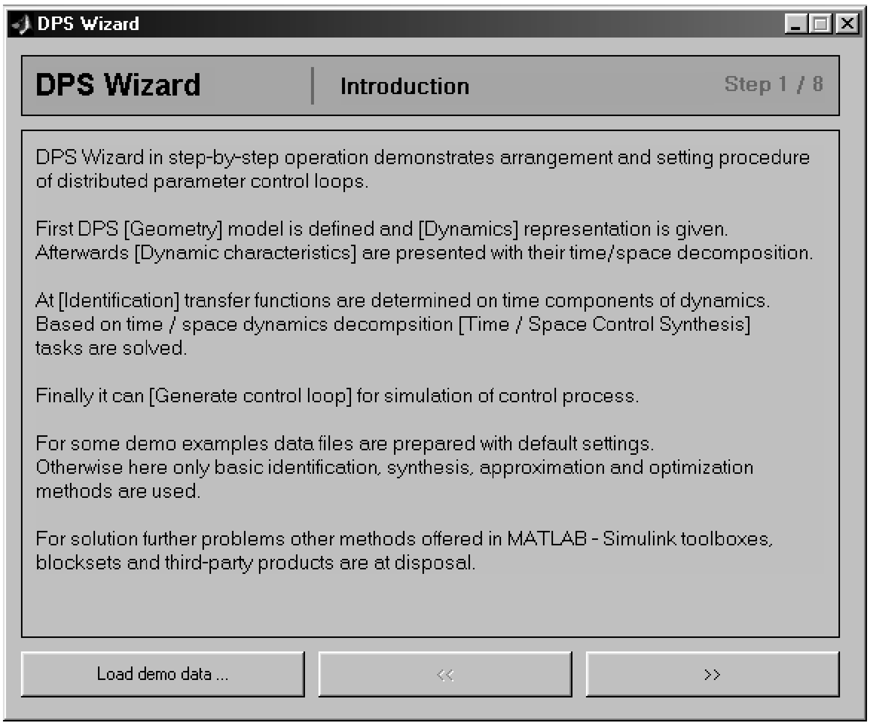

Fig. 10
Block DPS Wizard of the DPS Blockset for MATLAB & Simulink

The block **Tutorial** presents methodological framework for formulation and solution of distributed parameter systems of control.

The block **HLDS** models controlled distributed parameter systems as lumped input / distributed-output systems with zero order hold-units.

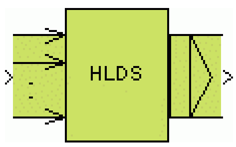

Fig. 11
Block HLDS of the DPS Blockset for MATLAB & Simulink

Through the **Dialog** distributed step responses of modelled system are provided into the block **HLDS**. Then, in the block parameters of distributed parameter model are adjusted. In the control loop the block **HLDS** assignes, to supplied lumped input variables, distributed output model quantities.

The **DPS Control Synthesis** provides feedback to distributed parameter controlled systems in control loops. The **space synthesis** is solved as an approximation problem and the **time synthesis** by **PID, Algebraic, State and Robust** controllers.

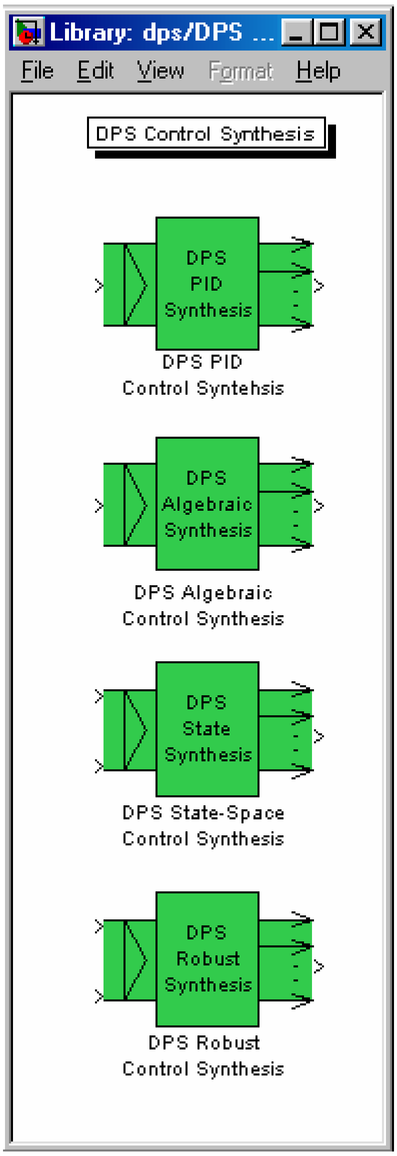

Fig. 12
Block DPS Control Synthesis of the DPS Blockset for MATLAB & Simulink

Through the **Dialog**-s distributed parameter step responses, time components of controlled system dynamics and some input parameters are required to load into blocks of **DPS Control Synthesis**. Then in blocks parameters of the approximation process and controllers are adjusted**.** In the control loop the **DPS Control Synthesis** blocks assignes to supplied distributed control errors sequences of actuating quantities.

5 Control of Complex Shape Metal Body Heating

Now, some possibilities, which the DPS Blockset offers by control of metal body heating will be indicated, Fig. 13. The dynamical model of metal body heating is given by numerical structures based on finite element method in FEMLAB. By means of blocks of the DPS Blockset a distributed parameter control loop is arranged, Fig. 14.

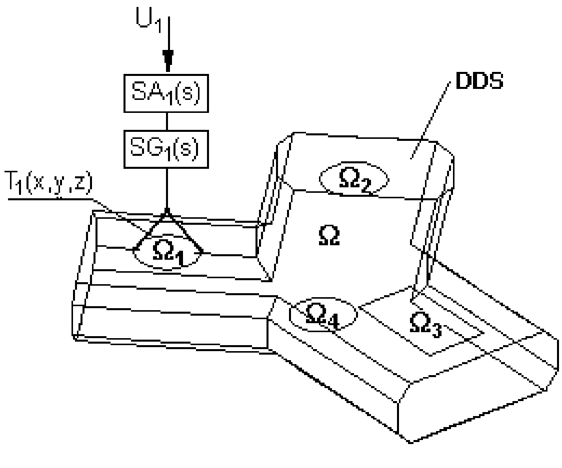

Fig. 13
Heating of metal body of complex shape: $\{SA_i(s)\}_i$ - actuating members with lumped input variables, $\{SG_i(s)\}_i$ - generators of distributed input variables, $\{T_i(x,y,z)\}_i$ - shaping units in space domain on $\{\Omega_i\}_i$, DDS - distributed-input/distributed-output system on the Ω, $\{U_i\}_i$ – lumped input quantities

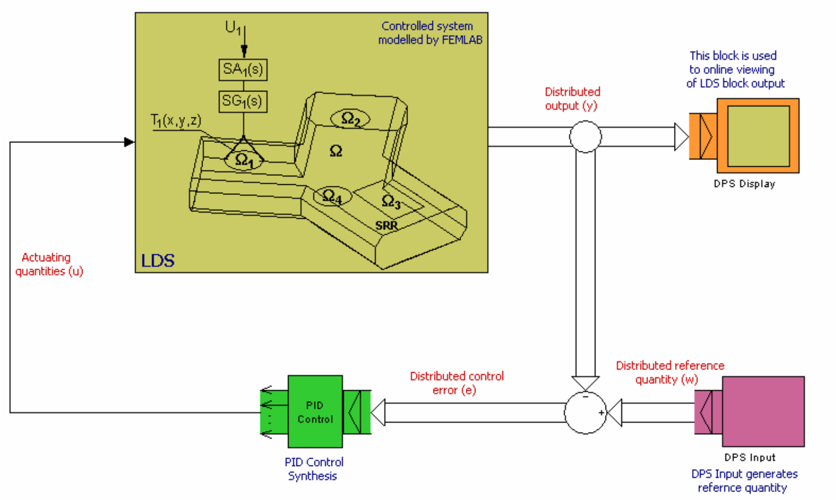

Fig. 14
Distributed Parameter Control Loop

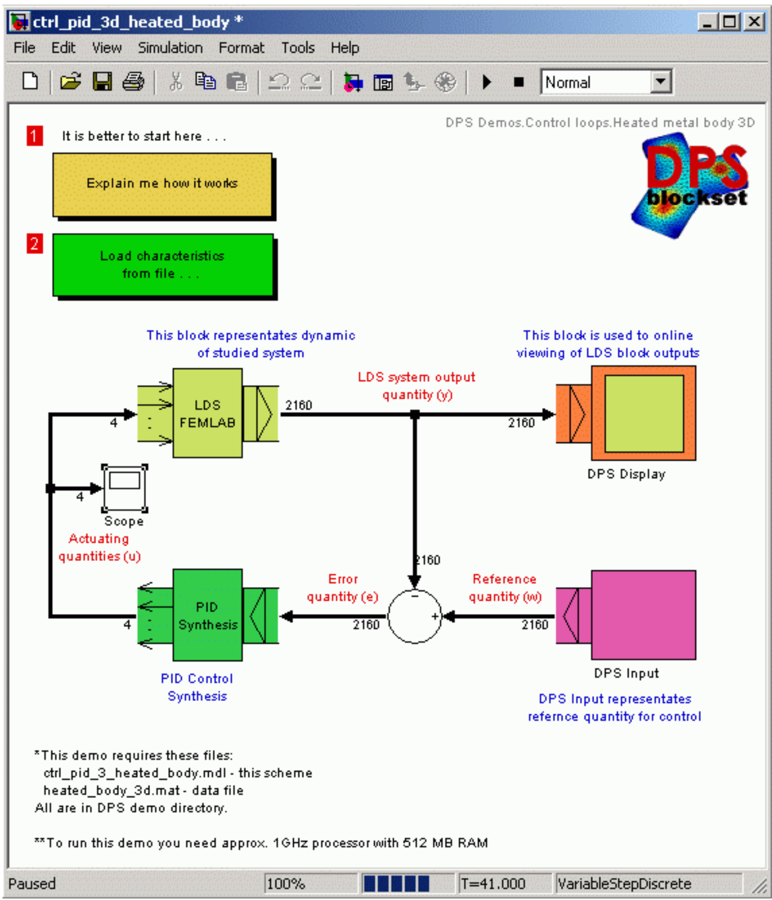

Fig. 15
Distributed parameter control loop in the DPS Blockset

Distributed quantity is represented by temperatures computed at node points of the numerical net. In this case it means 2160-element vector at node points and values between node points are computed by spline functions. Control process simulation results are in Fig. 16.

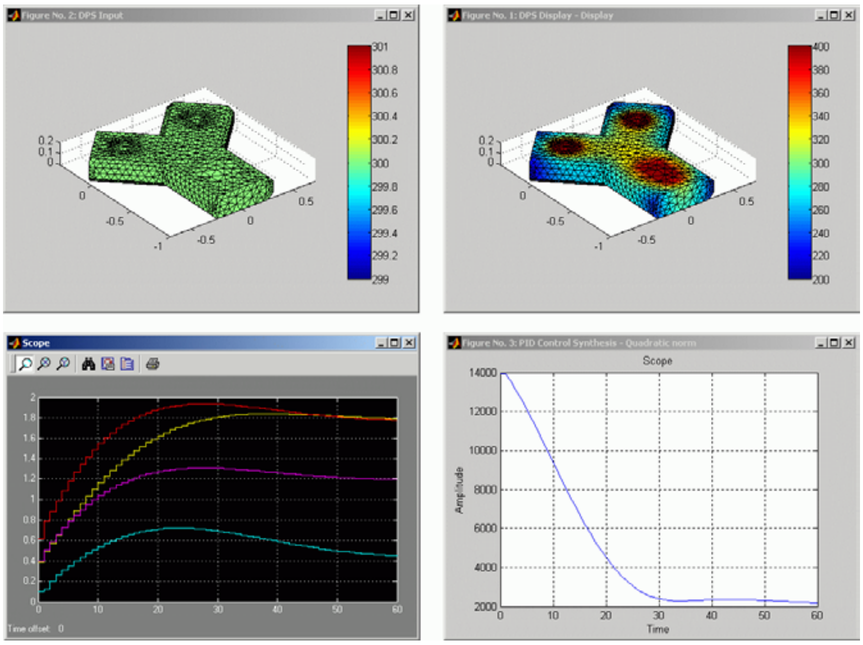

Fig. 16
Process of control : **a/** W(x,y,z,∞) - distributed reference quantity; **b/** Y(x,y,z,t) - distributed controlled quantity; **c/** $\{U_i(t)\}_i$ - actuating variables; **d/** E(t) - quadratic norm of distributed control error E(x,y,z,t)

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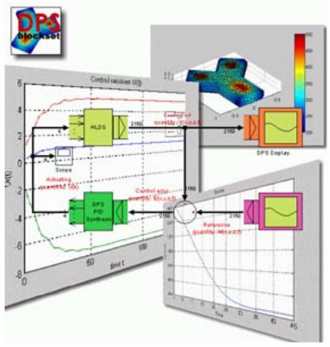
Distributed Parameter Systems Blockset for Simulink

Suite of blocks for control of distributed parameter systems

Highlights:

- Engineering methods for Distributed Parameter Systems (DPS) control
- Lumped-input/distributed-output systems
- Time/space analysis, synthesis and design tools
- Suites of blocks for engineering control problems solutions
- DPS Wizard for step-by-step arrangement of control systems
- Internet monograph and interactive service for support solutions

Description:



The Distributed Parameter Systems Blockset (DPS Blockset) extends Simulink with a comprehensive library for distributed parameter systems and their applications in modeling, control, and design of dynamical systems with complex 3-D domains of definition. An included demonstration presents some typical problems of DPS control from areas of technological and production processes, mechatronics, and protection of the environment. A tutorial and demos initiate users in DPS control problems. The DPS Wizard presents step-by-step procedures for arranging and setting control loops.

Blocks for time/space dynamical decomposition and synthesis offer flexible engineering methodology for DPS control.
The DPS Blockset is designed for engineers, researchers, and students who deal with dynamics and control of real world phenomena and processes.

Platforms: Windows

MathWorks products required: MATLAB, Simulink, Control System Toolbox, Partial Differential Equation Toolbox, Robust Control Toolbox, System Identification Toolbox

Support: Consulting, E-mail, Fax, Telephone

Application Areas:

- Aerospace and Defense
- Automotive
- Control Design
- Education
- Finite Element and Structural Modeling
- Process Control and Monitoring
- Simulation
- Vibration Analysis and Control

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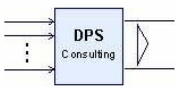

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