

DYNAST - modeling toolbox for MATLAB formulating equations automatically

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Introduction

No doubt, MATLAB together with SIMULINK and its toolboxes makes a very useful software package for control design. However, manual formulation of equations required for modeling complex systems and converting the equations into a block diagram is rather laborious and cumbersome unless the models are made sufficiently abstract and idealized. Efficient exploitation of a computer means using it not only for solving equations underlying the system models, but also for automated formulation of the equations.

This may not be so much visible in control design at the first sight. This need sign at the first sight. The 'functional models' suitable for control synthesis are usually rather simple as their complexity is constrained by the capability of the available control-synthesis methods. However, the control synthesis is just one step in the practical control-design procedures applied to real-life systems in an industrial environment. Within these procedures, the control-synthesis outcomes must be verified and revised in an iterative way using system prototypes.

'Virtual prototyping' based on simulation experiments is usually less expensive and time consuming than construction of real prototypes and their experimental verification by measurements. (The 'hardware-in-the-loop' approach can be used only if the plant to be controlled is available in the 'hardware' form already.) Virtual prototypes in the form of 'physical models' must mimic, however, the designed systems much more realistically than the functional models.

Besides this, virtual prototyping requires a unified multidisciplinary approach to modeling because of the nature of modern machines, instruments and other engineering systems. Simultaneous application of expertise from mechanical, electrical, control, computer and other engineering disciplines must be usually applied in the development of such systems. Mechatronics -- a new design philosophy based on a synergistic integration of the traditional engineering disciplines -- has been introduced just for this purpose.

To make physical modeling and virtual prototyping easier, we have developed a simulation package called DYNAST many years ago and have been improving it since then. After making DYNAST accessible across the Internet, we have been asked by the Technical Committee on Computer Aided Control System Design [1] of the IEEE Control Systems Society to set up the Virtual Action Group for Multidisciplinary System Simulation [2]. Because of dynamic HTML and Java applets, these websites are best viewed with Netscape. DYNAST and its environment can be accessed from [3].

Access to DYNAST

You can experience using DYNAST as a physical modeling toolbox for MATLAB and SIMULINK installed on your own computer by linking them across the Internet to DYNAST installed on our server.

After setting up a physical model of the real system you want to control, you can

- to submit data of the model to your MATLAB for control design, and/or
- to control digitally the model implemented in DYNAST by your SIMULINK.

A Web-based, on-line and e-mail access has been provided to DYNAST across the Internet. The Web-based access allows you to submit your problem to DYNAST via the Web either in

- a textual form or
- a graphical form using the DYNCAD schematic capture editor (a Java applet)

Then you will receive the required computational results (hopefully) in a tabular as well as in a graphical form.

The on-line access assumes that you have downloaded the DYNAST user's environment on your IBM compatible PC computer while the solver remains remote. Then the user's environment allows you to exploit DYNAST in the same comfortable way as if the complete package is installed directly on your computer.

The e-mail access was designed for those with limited access to the Internet. After sending an e-mail containing your input data for DYNAST to

`dynast@icosym.cvut.cz`, subject: compute,

you should receive the results sent back to your e-mail address automatically.

Modeling in DYNAST

DYNAST allows for setting up models of engineering systems from system parts in a kit-like fashion based on a mere inspection of the real systems in the same way in which the systems are assembled from real components. DYNAST formulates all the equations respecting the physical laws governing mutual energetic interactions between the components automatically.

The unified modeling and simulation of mixed energy-domain systems in DYNAST is based on the multipole approach. The multipole model of a real

system is a mapping of the system geometric structure onto its topological structure. Each multipole models the energetic interactions between a system component and the rest of the system assuming that the interactions take place just in a limited number of energy entries like electrical terminals, pipe inlets, mechanical or thermal contacts, shafts, etc. The energy flow through each such entrance is represented by a product of two complementary physical quantities - a through variable and an across variable: force - velocity, torque - angular velocity, volume flow - pressure, current - voltage, entropy flow - temperature, etc. (No bond graphs need to be constructed, however.)

DYNAST is accompanied by a library of multipole submodels of many typical components. The library is open in the sense that the users can add their own models or model modifications. The component models can be characterized by sets of algebraic-differential equations, by tables of measured data, by multipole and/or block configurations, or by a mixture of these. Using DYNCAD -- the DYNAST companion for submitting models to DYNAST in a graphical form -- you can also design your own graphical symbols for the submodels.

What DYNAST can do for you

DYNAST simulates nonlinear systems, i.e., it computes transient as well as steady-state responses, either static or periodic. The static steady-states can be computed for a system- or ambient-parameter sweeps through an interval. Fourier analysis of periodic responses is also available. The transient responses can start either from initial conditions specified by the user, or from initial conditions corresponding to a static or periodic steady-state.

DYNAST provides also automatically linearized system models that can be subjected to small-excitation analysis in the vicinity of the user-specified or computed quiescent operating point. This analysis yields operator functions representing either system transfer functions or transforms of system initial-state responses. These operator functions are available in a semisymbolic form with the Laplace operator s as a symbol, and with the polynomial roots (poles and zeroes) and coefficients as numbers. For such operator functions, DYNAST can compute semisymbolic- and numeric-form time- and frequency-domain characteristics.

DYNAST is well used already in numerous research, industrial and educational institutions to design engineering systems like

- electric and magnetic circuits
- mechanical and vibration systems
- electro-mechanical and automotive systems
- fluid power, pneumatic and acoustic systems
- heat-transfer and thermodynamic systems
- systems with energy transducers and sensors

Number crunching

To solve the resulting nonlinear algebraic-differential equations, DYNAST uses a stiff-stable backward-differentiation formula. The length of the integration steps and, at the same time, the order of the method are varied during the integration to minimize the computation time while respecting the permissible computational error. The equation jacobians are evaluated using a symbolic differentiation procedure.

Considerable savings of computational time and memory are achieved also by exploiting the jacobian sparsity. Thanks to the implicit form of the equations and to their simultaneous solving, DYNAST imposes no restrictions on the system structure. There is no need for equation sorting to solve the causality or algebraic loop problem.

DYNAST runs under MS Windows and Unix. It is distributed in single-user as well as in server versions suitable for engineering teams and computer classrooms. Its student version is distributed free of charge.

DYNAST user's environment

Besides the schematic editor DYNCAD, the DYNAST user's environment includes

- on-line User's Manual
- collection of interactively solvable examples
- Web-based course on multipole modeling
- automated LaTeX documentation system
- syntax analyzer to check input data
- Wizard helping users to submit the data
- data converters for MATLAB, OrCAD and Maple
- 3D animation of simulated object using VRML

References

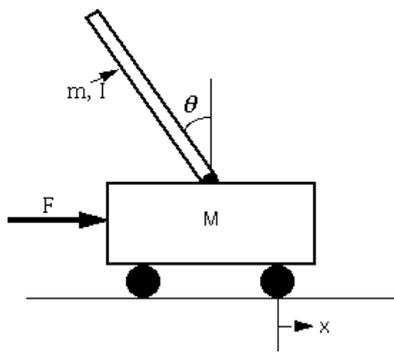
- [1] The Technical Committee on Computer Aided Control System Design of the IEEE Control Systems Society
<http://www-er.df.op.dlr.de/cacsd/>
- [2] The Virtual Action Group for Multidisciplinary System Simulation
<http://icosym.cvut.cz/cacsd/msa/>
- [3] Web-Based and On-Line Simulation Tools
<http://icosym.cvut.cz/cacsd/msa/onlinetools.shtml>
- [4] Control Tutorials for MATLAB, University of Michigan
<http://www.engin.umich.edu/group/ctm/>

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CZ-160 00 Prague 6, tel/fax +420-2-3117904

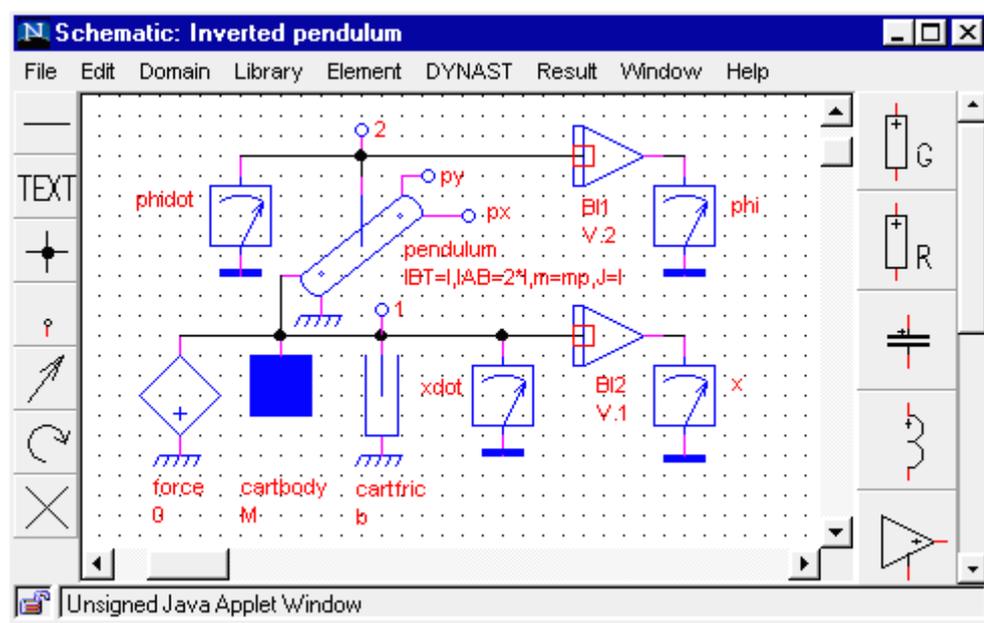
dyn@vc.cvut.cz

Example: Inverted Pendulum Experiment

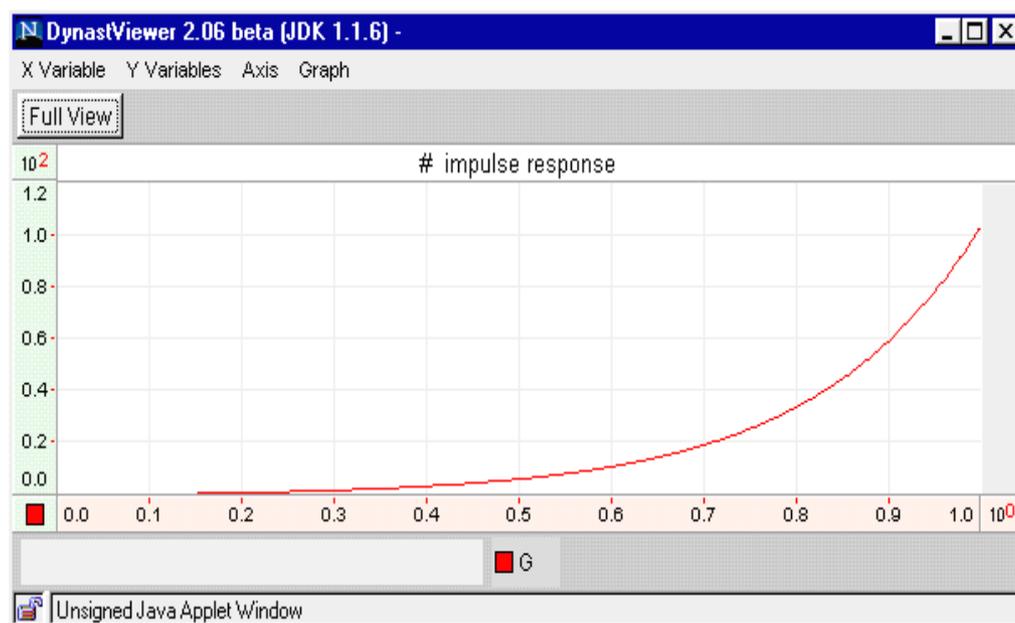


To demonstrate the efficiency enhancement of the control design using DYNAST as a modeling toolbox for MATLAB let us consider a controlled plant in the form of the inverted pendulum given above. For the detailed problem setup, please, have a look at [6].

Instead of writing down the differential equations characterizing the plant dynamics, the following dynamic model can be easily set up using the Web-based DYNCAD schematic editor. The models consists from the library model of a mechanical link with two rotational joints and from primitive elements like a mass, ideal damper, force actuator, integrators and velocity as well as position measuring virtual instruments.



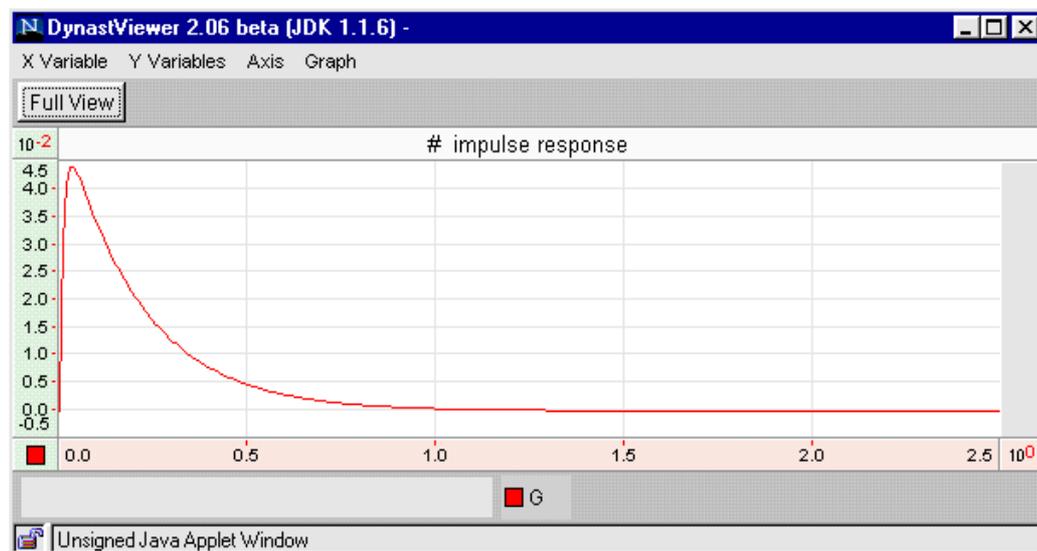
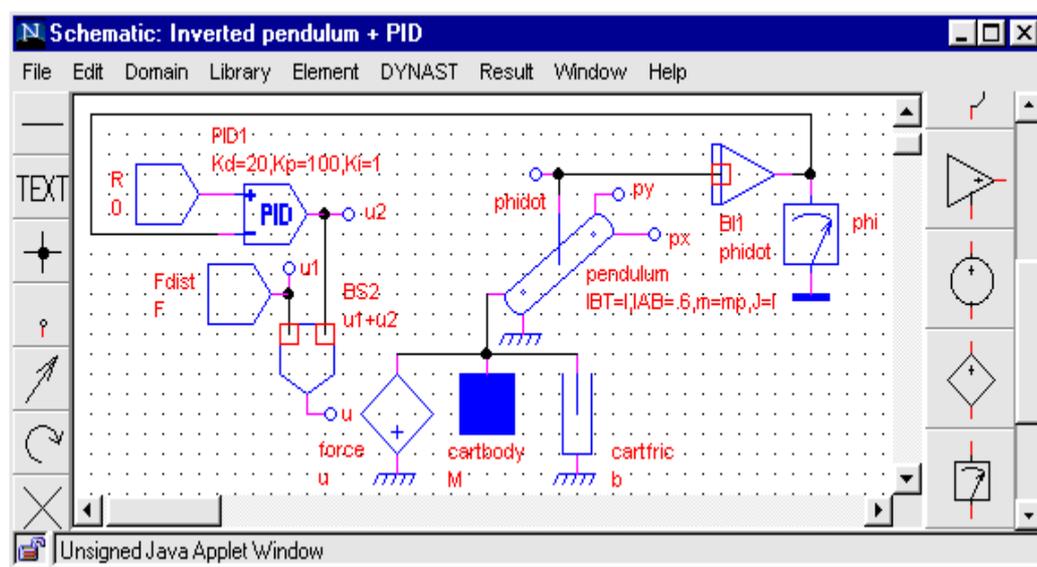
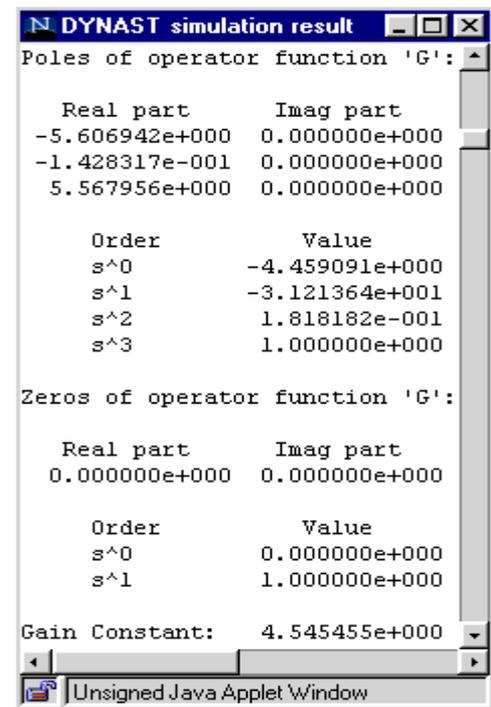
DYNAST then can computes the impulse response of the uncontrolled plant and displays it as



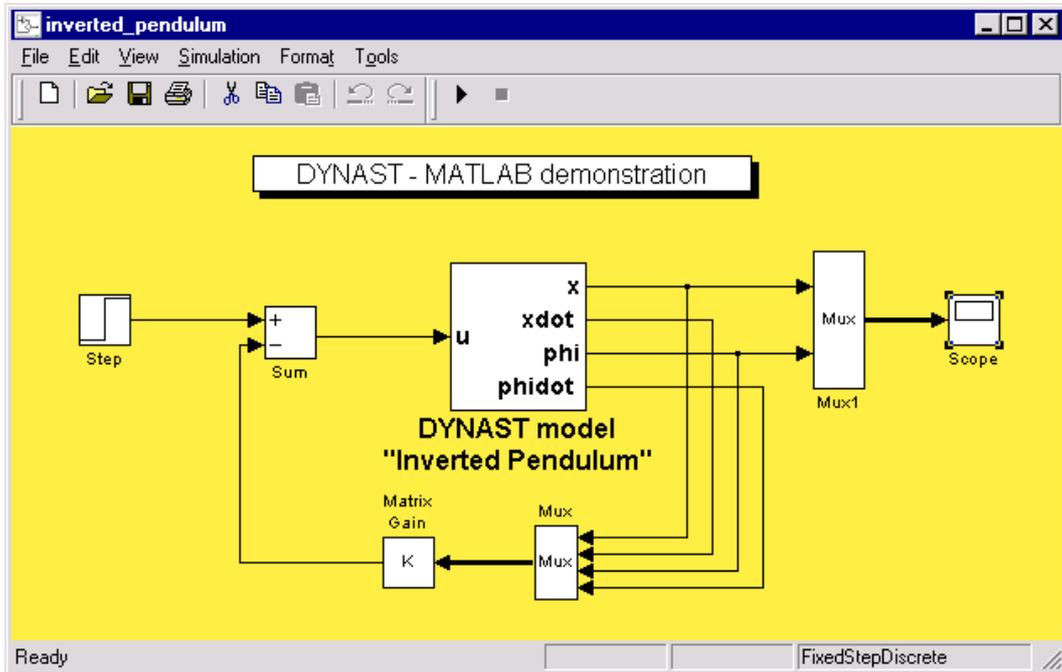
To design the control, the plant transfer function poles and zeros are needed. This would require manual linearization of the differential equations, converting them into their normal form and then into a transfer function. Only after all this the transfer function can be submitted manually to MATLAB to compute its poles and zeros.

Thanks to DYNAST, however, the poles and zeros can be computed for the above given model without any manual intervention and transferred then into MATLAB for control design directly in the form of an M-file.

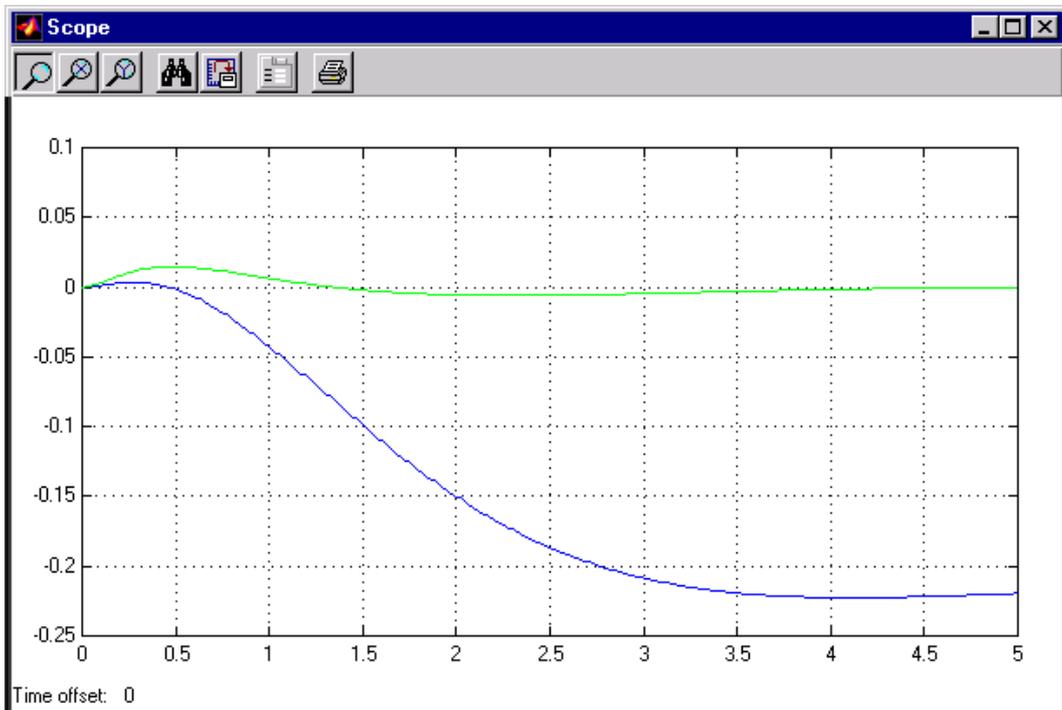
After designing the PID control, for example, the plant can be augmented in DYNCAD by the controller as shown below and then the resulting system can be verified by computing its impulse characteristic.



A similar procedure can be taken for digital-control design. To verify the design in this case, SIMULINK can be linked to DYNAST across the Internet after downloading some small software modules. The control configuration is then implemented in SIMULINK as shown below, while the plant model stays in DYNAST -- the square block in the middle. The interconnections denoted by the line segments between the square block and the other blocks represent the interconnection between DYNAST and SIMULINK via the Internet.



After starting simulation in SIMULINK the following responses of the pendulum angle and the cart position are obtained.



This and other more sophisticated examples can be found on [3].

New examples are most welcomed. After receiving them from you we will be pleased to publish them on the Web with your name(s).