VIRTUAL PID TOOLBOX (VPT)

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Abstract

The paper deals with the development of a program system for modeling, control, simulation and animation of various controller and control loop types (feedback, feed forward, ratio and combination of individual structures). The program system enables the user to generate optimal controller structures and compute optimal controller parameters based upon more than 30 tuning methods with and without knowledge of the mathematical model. In the first stage based upon measured data or the known mathematical model, the program system performs optimal identification and possible reduction of the mathematical model (10 etalon model types). The second stage is the controller structure design (PID, LQ, LQR, generalized polynomial,....). Using the VPT it is possible to choose arbitrary theoretical or industrial controller (considering different controller vendors); for the chosen controller the program system computes optimal parameters and realizes graphical and numerical performance and stability tests in both time and frequency domains. In the modular form the Virtual Toolbox was applied for the modeling and tuning controller parameters in power and gas industries. The program system VPT presents an effective extension to the existing Toolbox Control in Matlab and can be used e.g. as a supporting system in education and practical industrial controller tuning.

Keywords: Control methods, Complex systems, PID control, Deadbeat control, Algebraic polynomial control, MPC control, Virtual reality, Animation.

Štefan Kozák was born in Velaty, Slovak Republic, in 1946. In 1970 he obtained the Diploma in Electrical Engineering from the Slovak Technical University in Bratislava and in 1978 the Ph.D degree in Technical Cybernetics from the Slovak Academy of Sciences. Since 1976 he has worked at the Institute of Technical Cybernetics in the field of control algorithms design. He has led a research group in the Institute of Applied Cybernetics in Bratislava (1981-1984). Since 1998 he was Head of the Department of Automatic Control Systems, Faculty of Electrical Engineering and Information Technology in Bratislava. In 1989, he received pedagogical degree Assoc.Prof. In 2004 he was appointed professor (prof.). He chairs doctoral study in the field of Control Engineering at the FEI STU in Bratislava. His research interests include system theory, linear and nonlinear control methods, numerical methods and software for control and signal processing. He published over 200 research papers in conference proceedings and international journals, and organized several international IFAC conferences held in 1994, 1997, 2000, 2003 in the Slovak Republic.

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1. Development of Modeling and Control Methods and Algorithms

Automatic control systems are pervasive today. They appear practically everywhere: in our homes, industry, communications, information technologies, etc. Process control continues to be a vital, important field with significant unresolved research problems and challenging industrial applications. The present trends in the process control require an increasing degree of integration. Any effort to maintain the optimal operation results in a requirement to increase flexibility in control layers. Furthermore, increasing problems with interactions, process non-linearities, operating constraints, time delays, uncertainties, and significant dead-times consequently lead to the necessity to develop more sophisticated control strategies capable to be incorporated into the software package following the present software engineering lines.

Control systems design is currently undergoing an interesting phase of development and implementation in industrial plants. The driving force of it is the drastically increased computation ability offered by digital computers and highly powerful 16bite and 32bite microprocessors. Process control methods can be classified according to the level and degree of their use in industry. Most of the used industrial controllers are of standard PID type (in continuous and/or digital form). For practical implementation, only 10-12 basic algorithms are being used, modified according to the processor type, plant dynamics, time delays, etc. Moreover, in typical control processes (e.g. thermal processes, chemical processes, power plants, etc.) it is often necessary to modify the classical tuning methods taking into consideration the time delays, unmodeled dynamics, changes of working conditions and disturbances. Improvement of classical methods is possible under the assumption that the original control algorithm is extendable with respect to the changes in process parameters, yields closed loop stability even in the presence of large time delays and is applicable in the real-time control. The emphasis is placed on generalized discrete controllers designed as dead-beat controllers of classical type and/or algebraic polynomial controllers. The algebraic approach allows to design controllers with robust properties modifiable by IMC filters (with a feed-forward and a feedback structure as well).

The Model Predictive Control (MPC) is based on the process model, which approximates the control systems dynamics. As such, the model is a crucial part of the MPC algorithm. Not all formal models developed e.g. for process dynamics simulation purposes, are suited for the MPC scheme. Algorithms for deriving the control actions have to be specified. The objective is to specify the information, which will serve for process model derivation and parameter identification. There is always some kind of prior information, which can be supplied by the field engineer in terms of number of inputs and outputs, time constants, delays, static input-output characteristic, limits etc. Design of on-line tests providing information for model parameter identification is another objective for this phase. A distinctive characteristic of this class of methods is their ability to optimize some closed loop behavior measure by taking advantage of an explicit process model, while respecting at the same time the existing operational constraints.

2. Virtual Toolbox Structure

The main aim of the proposed program system VPT is to provide support for the designer during the preparation and implementation of different control algorithms. The program system for modeling, control, simulation and animation has the following structure:

A. Conventional Control Methods

Manual control

Feedback control (FB)

Cascade control (CC)

Ratio control (RC)

Feedforward control (FWC)

Combined FB, FWC

B. Advanced Control – Classical Methods

Adaptive control

Gain scheduling methods

Time delay comp. control methods

Multivariable-decoupling control

Selective/Override controllers

C. Advanced Control I

Model predictive control (MPC) (Linear, Nonlinear)

Statistical quality control (SQC)

Internal Model Control (IMC)

Adaptive and Self-tuning control methods (AC and STC)

D. Advanced Control II

Optimal control methods (LQ, LQG)

Nonlinear control methods (NC)

Robust control methods (RC)

Hybrid and discrete event control methods

Fuzzy control methods

Artificial neural control methods

Expert control systems

3. Modeling and control module

The following section shows how the mathematical model of the controlled processes can be obtained from measured I/O data or by offering various mathematical models in s-and z-domains or in the state space (Fig.1). If the VPT estimation procedure provides a too high order of the mathematical model, the program system enables to reduce this model to enable the computation of controller parameters. The second stage is controller coefficients comutation and the open loop and closed loop simulation for different models and different controller parameters computed. The program system recommends the user the best controller choice according to the specified performance criterion. For thermal processes, drivers, reactors, power plant it is also possible to animate the controller design and show the complex control loop design including control components.

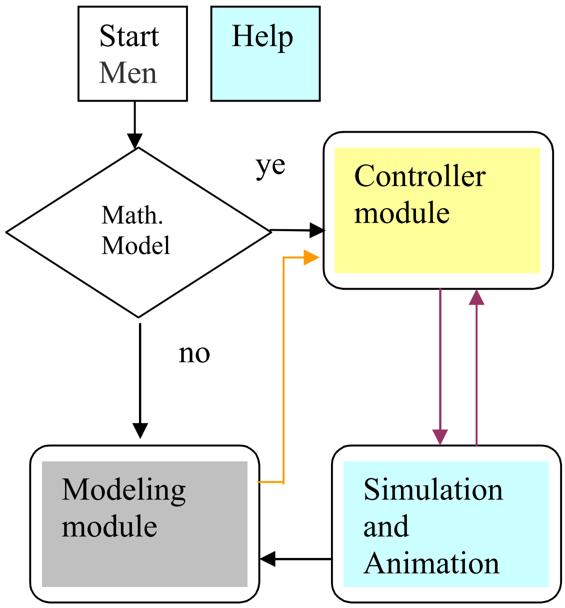

Fig. 1 Modular structure of the Virtual PID Toolbox

Modeling Module comprises mathematical model types which can be determined and estimated by the VPT program system:

Table 1 Modeling Module of VPT

Static models
- static - linear (SISO, MIMO)
- static - nonlinear (SISO, MIMO)
Dynamic – Continuous-time models
- dynamic - linear state-space
- dynamic - transfer functions s-domain

- dynamic - nonlinear differential equations
- dynamic - partial differential equations
Dynamic Discrete - event models
Dynamic – Discrete-time domain
- parametric identification I/O data
- recursive form (LLSQ, REFIL, LDFIL
- dynamic - transfer functions z-domain
- dynamic - difference equation
- dynamic - difference equation ARX
- dynamic - difference equation ARMAX
- dynamic - difference equation BJ
- dynamic - difference equation OE
- dynamic orthogonal models
- dynamic - non-linear difference equation NARMAX
Soft computing models
- dynamic - artificial neural network
- dynamic - fuzzy model
- dynamic - fuzzy-neuro

Controller module includes the following design methods:

PID (continuous/digital) different form
PID (continuous, CPID)
PID (digital, DPID) different form
Linear Feedback State Space Controller (continuous, LQR)
Linear Feedback State Space Controller (digital, DLQR)
Output Feedback State Space Controller (Continuous,OLQR)
Output Feedback State Space Controller (Digital, DLQR)
Direct Adaptive Controller
Indirect Adaprive Controller
Model Reference Adaptive Control
Selftuning Controller
Pole-placement State Space
Controller (Continuous, CPLP)
Pole-placement State Space
Controller (digital, DPLPl)
Algebraic PolynomialController (week version, APCV)
Algebraic PolynomialController (strong version, APSV)
Algebraic Polynomial Controller (fedback + feedforward, weak version, APFFV)
Algebraic PolynomialController(fedback + feedforward, strong version, APFFS)
Algebraic Polynomial Quadratic Controller
Robust PID Controller
Fuzzy PID Controller
Neuro PID Controller
Ziegler-Nichols off and online
Optimum Magnitude Method
Naslin Method
Frequency Methods
Inverse Dynamic Method
Standard Polynomial Methods
Cohen - Coon Method
Time Constants Method
Pole Placement Method
Tangent Methods
Model Predictive Control (MPC)
Robust Internal Control Method
Robust H_{inf}
Robust LMI
Learning Neural Netwok Control
Genetic Controller Design

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4. Demostration examples

Demonstration abilities of the program system VPT are shown in the next figures

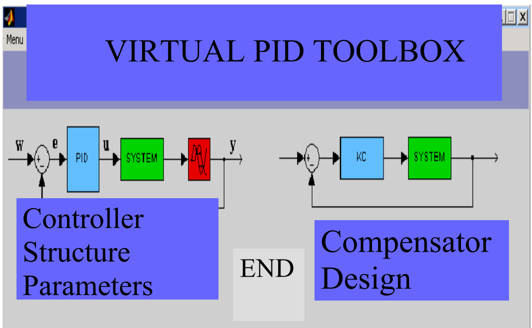


Fig.2 Controller design menu

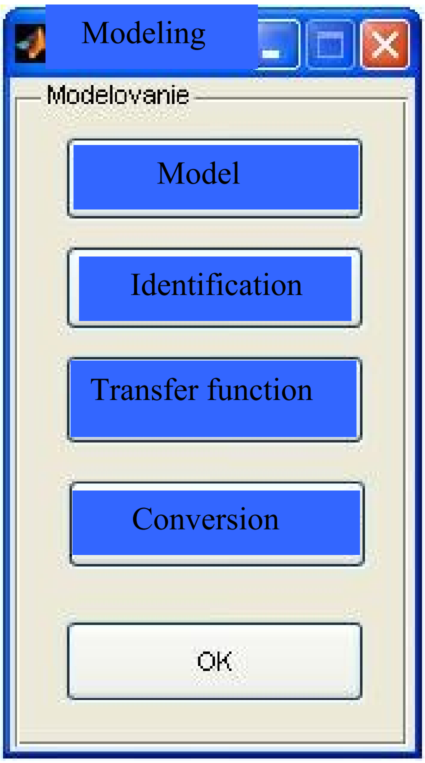


Fig.3 Main Menu for Modelling

Virtual Toolbox can be applied for various types of known industrial controller. Following figures show a demonstration of VPT Toolbox application for industrial controller parameters tuning. In cooperation with industrial partners in Slovakia, during the last 5 years the Toolbox VPT was applied in the thermal power plant Novaky for tuning parameters of a pressure controller of a boiler extended by a feedforward path from the turbine power. VPT Toolbox can be applied as an individual module and can be applied by the operator as a recommendation tool in critical situations. VPT Toolbox also includes advanced tuning techniques based on fuzzy logic, fuzzy-neuro and genetic algorithms.

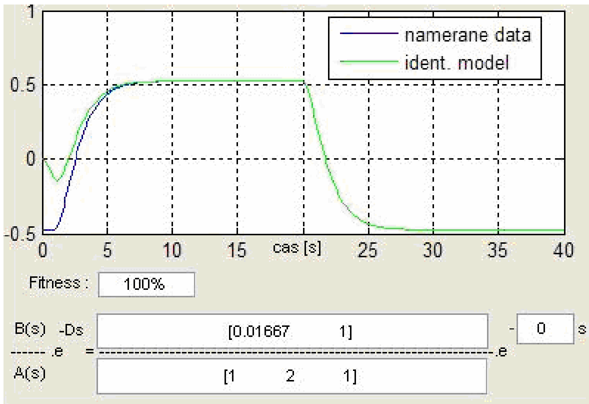
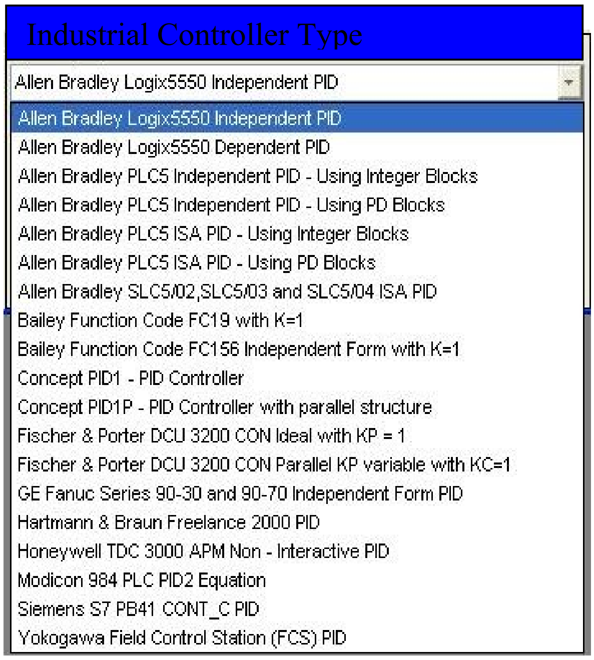


Fig 4 Demonstration of model identification using transfer function

Demonstration of controller parameter computation from VPT:

Table3 Industrial Controller Menu:



The simulation and animation module enables the user to compare various controller designs and choose the optimal design. The user can compare different methodologies for tuning controller parameters and the closed loop performance. The VPT Toolbox enables automatic selection of the best controller design. Numerical and graphical results of individual controller parameters computation can be shown in the time and the frequency domains.

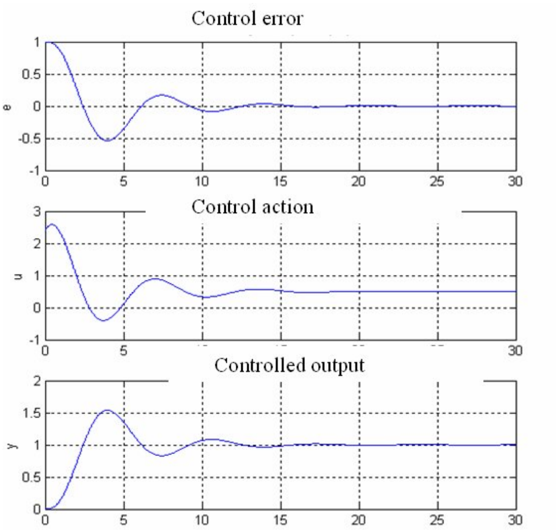


Fig.5 Time responses of control, control error and output provided by VPT

Virtual Toolbox was applied in 10 industrial processes for which virtual models were created. The following virtual models can be used as examples in education of control and modeling methods, and can be used to verify closed-loop performance for selected industrial controller:

VPT offers the following process types:

- Servodrive
- Electrical furnace
- Heat exchanger
- Gas blend
- Duplicator
- Ammonia production
- Smelt furnace
- Chemical reactor
- Bioreactor
- Brick production

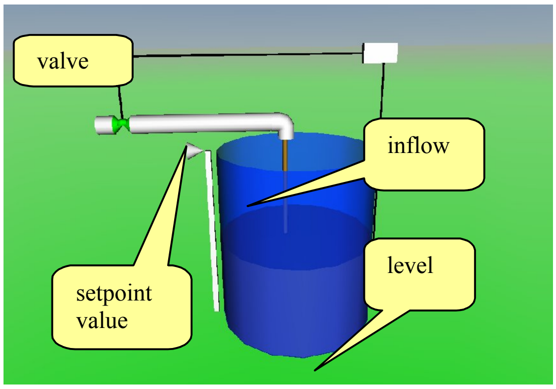


Fig. 7 Virtual model of water storage

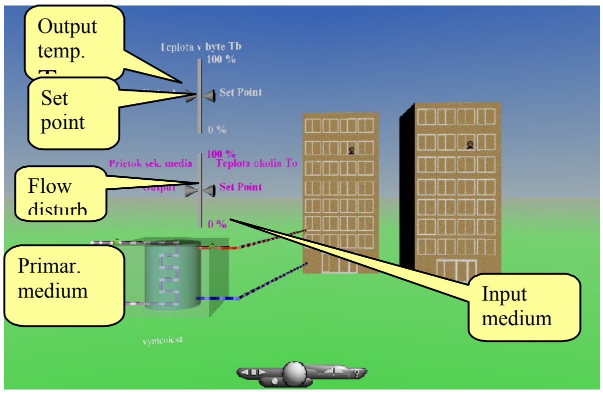


Fig.8 Virtual model for central heating

5. Conclusions

The paper deals with the design and development of a program system VPT for modeling, control, simulation and animation of various controller and control loop types. The program system enables the user to generate optimal controller structures and compute optimal controller parameters based upon numerous tuning methods with comparing of performance in numerical and graphical form.

6. Acknowledgement

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7. References

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