USING HYBRID SYSTEMS MODELING TO DESIGN A VENTILATION SYSTEM IN ROAD TUNNEL

Jozef Hrbček, Juraj Ždánsky, Vojtech Šimák

Department of Control and Information Systems, Faculty of Electrical Engineering, University of Žilina, Univerzitná 8215/1, 010 26 Žilina, Slovak Republic

Abstract

This paper engages in system modeling. Since the road tunnel is complicated system we are not able simply describe this system. We can describe this system as unification of different models according to Figure 1. This model is used for design the controller to optimize the current way of control.

1 Hybrid system modeling

Hybrid systems are dynamic systems with both continuous-state and discrete state and event variables, i.e. the plant has time-driven and event-driven dynamics, the controller affects both time-driven and event-driven components and it may deal with continuous *and/or* discrete signals. The approach taken by the computer science community to model hybrid systems has been hybrid automata. Hybrid automata are finite state machines where a continuous dynamics is associated to each discrete state. They are composed of a set of discrete states X_d and a set of continuous states X_c. Discrete state changes can be produced by changes of the discrete inputs, or when the continuous state (augmented by the input signals) enters or exits determined regions.

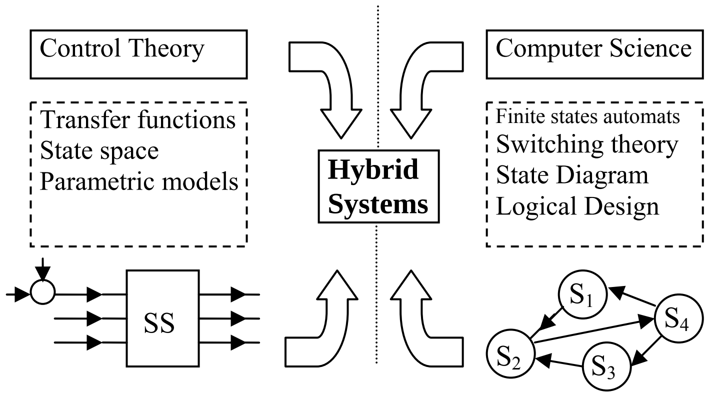


Figure 1: Hybrid systems

2 Application to Road tunnel system

Data characterizing the existing ventilation system can be used to analyze and identify the significant parts of system and create its stochastic and deterministic models. Inputs values are traffic volume, atmospheric pressure, velocity and output values are CO (carbon monoxide) concentration, NOx (nitric oxides) concentration and opacity inside the tunnel [7]. Measured data come from the road tunnel in Prague [10].

The ventilation system represents one function unit designed as longitudinal ventilation with a central efferent shaft and protection system avoiding spread of harmful pollutants into the tunnel surround area. Ventilation is longitudinal facing in direction of traffic with air suction at the south opening of the eastern tube (ETT) and at the branch B (see Figure 2.), with air being transferred at the north opening to the western tunnel tube (WTT) [7]. The eastern tunnel tube (ETT) has been chosen as a model example due to principle of mixing polluted air from ETT to WTT (measured concentrations of pollutants in the WTT are also influenced by traffic intensity in the ETT).

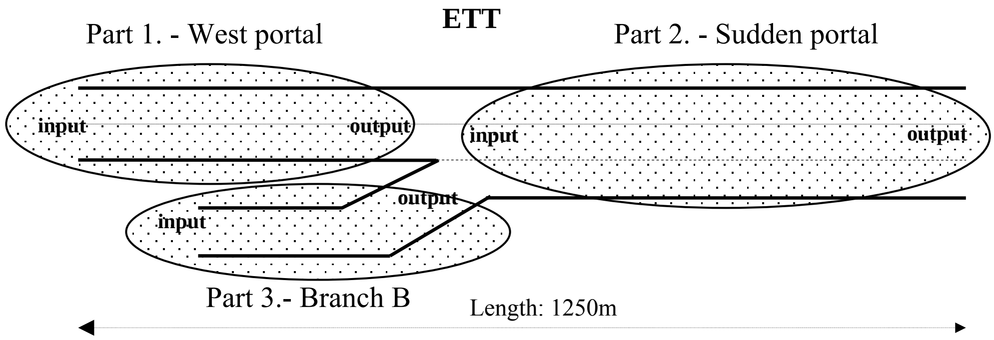


Figure 2: Dividing of the ETT tunnel to three separate parts

2.1 Transfer function model

A transfer function is a mathematical representation of the relation between the input and output of a (linear time-invariant) system. For Single-input Single-output (SISO) Linear Systems we have the equation [3]:

$$\frac{Y(s)}{U(s)} = G(s) \quad (1)$$

Discrete-time systems can be entered directly in a way analogous to continuous-time systems. The sampling time is required as an additional parameter. For instance, for the sampling time $h = 0{:}1$, the a zero-order hold model of an integrator, $H(z) = h{=}(z - 1)$. Continuous-time systems can be converted to discrete-time systems by using the MATLAB function c2d.

2.2 State space model (SS)

The state-space representation of a linear system with p inputs, q outputs and n state variables is written in the following form [1]:

$$\overline{\mathbf{x}}'(t) = \overline{\mathbf{A}}(t)\cdot\overline{\mathbf{x}}(t) + \overline{\mathbf{B}}(t)\cdot\overline{\mathbf{u}}(t)$$
$$\overline{\mathbf{y}}(t) = \overline{\mathbf{C}}(t)\cdot\overline{\mathbf{x}}(t) + \overline{\mathbf{D}}(t)\cdot\overline{\mathbf{u}}(t), \quad (2)$$

where **A** is the "state matrix", **B** is the "input matrix", **C** is the "output matrix" and **D** is the "zero matrix".

2.3 Logic function

The discrete (usually logical) parts of the systems can be described by discrete automata and defined by the following 5-tuple $[X, U, Z, \phi, \lambda]$, where X is the finite set of possible states and U and Z are the finite steps of possible inputs and outputs. The transition function δ: $X\times U\rightarrow X$ defines the next state of the system ($x(t+\delta t) = \phi(x(t), u(t))$). The output function λ: $X\times U\rightarrow Y$ describes the output of the system as a function of the state and input (when the Mealy model is used) or just the state (when the Moore model is used). Functions δ, λ are logical functions and can be defined by logical expressions or truth tables. The time interval δt appearing in the state transition equation may be dictated by a clock in the case synchronous systems or by occurrence of a particular system in the case of asynchronous systems.

2.4 Fans characteristics

Model of jet fan in transfer functions representation, obtained by identification is:

$$\begin{bmatrix} y_1(k) \\ y_2(k) \end{bmatrix} = \begin{bmatrix} G_1(k) \\ G_2(k) \end{bmatrix} \cdot u(k) \quad (3)$$

$y_1(k)$ ~ reduce CO concentration: $$G_1(s) = \exp(-10s)\frac{-0.19}{s^3 + 20s^2 + 95s + 1} \quad (4)$$

$y_2(k)$ ~ *reduce OP concentration*: $$G_2(s) = \exp(-30s)\frac{-0.011}{500s^2 + 60s + 1} \qquad (5)$$

These characteristics express how affect the one switched on fan to pollution inside the tunnel tube.

2.5 Pollution characteristics in Part 2.

Model of pollution acting in ETT (in Part 2. - Sudden portal) in state space representation, obtained by identification is shown in block diagram:

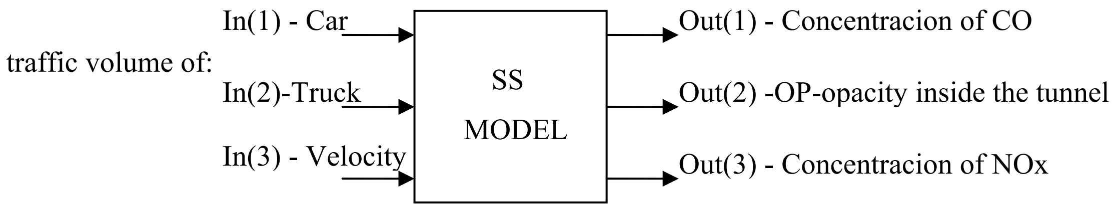


Figure 3: Block diagram of the eastern tunnel tube: part 1.

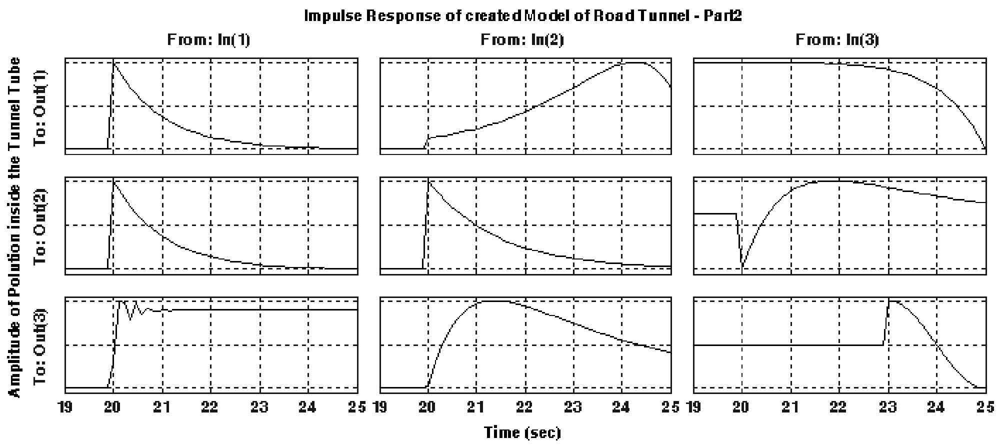


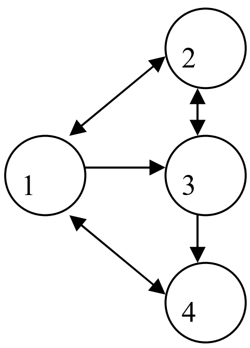
Figure 3: Outputs characteristics (impulse response)

Each parts of ETT have been created his own state space model for monitored values. The time delay between input and output in Part2 is approximately 20 sec, in Part1 it is 15 sec and time delay in Part3 is 6 sec. Other significant values can be included in others types of models.

2.6 Tunnel Modes

Tunnel Modes

Model of Tunnel Modes can be express by state diagram:



1 - normal state;

2 - a state of emergency;

3 - in a state of disrepair;

4 - state of maintenance and repair.

2.7 Coefficient of determination

We can express the square of the correlation coefficient between inputs and outputs variables. This value represents the fraction of the variation in one variable that may be explained by the other factors. In our study we got the result, that traffic volume cause about 60 to 90 percent to final values of concentration inside the tunnel. We want determinate how affect the atmospherics and velocity to pollution and make connection between these models.

3 Results

The existing tunnel system was identifying using methods for system identification. This part is the ground for best design of ventilation control system.

4 Conclusion

The paper presents a methodology that has been used for design the predictive controller of road tunnel ventilation. We used the data obtained from the real ventilation system. Models of road tunnel system has been created, simulated and verified in MATLAB environment.

This work has been supported by the Grant Agency VEGA of the Slovak Republic, grant No. 1/0023/08 "Theoretical apparatus for risk analysis and risk evaluation of transport telematic systems".

References

[1] CAMACHO, E. F., BORDONS, C.: *Model Predictive Control*. 2nd ed., Springer-Verlag LondonLimited, (2004) 405. ISBN 1-85233-694-3
[2] MACIEJOVSKI, J.M.: *Predictive Control with constrains*, (2002) 331p. ISBN: 0-201-39823-0
[3] JOHANSON, R.: *System modelling and identification*, Prentice-Hall, (1993) 512. ISBN: 0-13-482308-7
[4] HRBČEK, J.: *Active Control of Rotor Vibration by Model Predictive Control – a simulation study*. Report 153, Picaset Oy, Helsinki (2007), ISSN: 0356-0872
[5] GODAN, J. at al.: *Tunnels, Road Tunnels and Railway Tunnels,* 2001, p. 202. 135882/p-UK/Z
[6] PŘIBYL, P. - JANOTA, A. - SPALEK, J.: *Analysis and risk management in traffic. Surface Traffic and Railroads.* BEN Praha (2007) 515. ISBN 80-7300-214-0
[7] PAVELKA, M.- PŘIBYL, P.: *Simulation of Air Motion and pollutions inside the Road Tunnel– Mathematical Model*, OPTUN 228/06-EEG (2006)
[8] Ivančić, F.: *Modeling and Analysis of Hybrid Systems.* A Dissertation in Computer and Information Science, University of Pensylvania, 2003, p. 254
[9] NOSKIEVIČ, P.: *System Modelling and Identification*, Ostrava: MONTANEX, a. s. (1999) p. 276. ISBN 80-7225-030-2
[10] Hrbček, J.: Parametric Models of Real System and the Validation Tools, In: *Proc. 8th European Conference of Young Research and Science Workers in Transport and Communications technology.* p. 93-96. Žilina: June, 22. – 24. 2009. ISBN 978-80-554-0027-3

Jozef Hrbček
ŽU, EF, Department of Control and Information Systems, e-mail: hrbcek@fel.uniza.sk

Juraj Ždánsky
ŽU, EF, Department of Control and Information Systems, e-mail: juraj.zdansky@fel.uniza.sk

Vojtech Šimák
ŽU, EF, Department of Control and Information Systems, e-mail: vojtech.simak@fel.uniza.sk