Educational software for the simulation of virtual dynamical systems

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Abstract

In this paper some aspects regarding the implementation of the control algorithms for virtual processes are presented. Virtual reality represents an easy approach to study the behaviour of the process. Using virtual reality one can achieve knowledge about the influence of the input and the output signals on the dynamical systems. Along the implementation of the virtual system it is necessary to do a solid modelling of all essential aspects of the real process. However, the virtual system is included into a control loop. Also, the actuator of the control loop is a virtual system and it can be servomotor, DC motor or step by step motor. The behaviour of the virtual actuator is based on the mathematical models or the static characteristic. To achieve compatibility between virtual systems and real systems it is required a card acquisition for the signal's adaptation. This educational software has two advantages. Firstly, when using the card acquisition, the virtual approach is very similar to the real one. In the virtual approach the control of the virtual system is made with electrical signals. Secondly, it is possible to analyze the system when reaching its limits.

Keywords: Educational software, virtual process, virtual reality, modelling

1. Introduction

Virtual reality is an artificial environment that is created with software and presented to the user in such a way that the user suspends belief and accepts it as a real environment. The simplest form of virtual reality is a 3D image that can be explored interactively at a personal computer, usually by manipulating hardware interfaces (Kovach, 1997; Peterson, 2001).

A VR application is made of different components (Burdea and Coiffet, 2003; Vince, 2004) which can be described as:

a) **The scene and the objects.** The scene corresponds to the world in which the objects are located. VR contains lights, viewpoints and cameras. The objects have a visual representation with colour and material properties.

b) **Behaviours.** The objects may have behaviours (Willans, 2001). For instance, they can move, rotate, change size and so on.

c) Interaction. The user must be able to interact with the virtual world and its objects. For instance, a user can pick up some objects or he can drag an object. This may be achieved by means of a regular mouse and keyboard or through special hardware such as a 3D mouse or data gloves (Vince, 2004).

d) **Communication.** Nowadays, more and more VR applications are also collaborative environments in which remote users can interact with each other. To achieve this, network communications is important.

e) **Sound.** VR applications also involve sound. Some research has been done over the last 20 years in order to simulate sound in VR application. In this paper, the modelling of the sound will not be addressed.

The developing of the different components of a VR application is not an easy task and during the last twenty years, a number of software tools have been created to ease the developer's task. These tools can be classified into authoring tools and software programming libraries. Virtual reality can be used for the simulation of a real environment in training and education and for the development of an imaginary environment in a game or interactive story.

The most important applications of the virtual systems are those used for training flight pilots, drivers and ship commanders (Wolffelaar and Winsum, 1995). Besides the basic training, the simulators can be used for training in risky situations that cannot be exercised in real life. This paper contains educational virtual processes used for system analysis and synthesis of the command. The connection between the virtual process and the control computer is done using a hardware interface. In this way system analysis and system control are identical with the real system from the user's point of view.

2. The components of a virtual system used in the analysis of dynamic systems

The virtual systems (Willans and Harrison, 2001) used in this educational software allow the analysis of the dynamic systems using the same input/output sizes of a real system. In this way the control software for the virtual system is 100% compatible with the control software for the real system. Besides other advantages, the virtual process allows the user to train in limit conditions without affecting or damaging the system.

The structure of a virtual process used in the educational software is shown in figure no. 1.

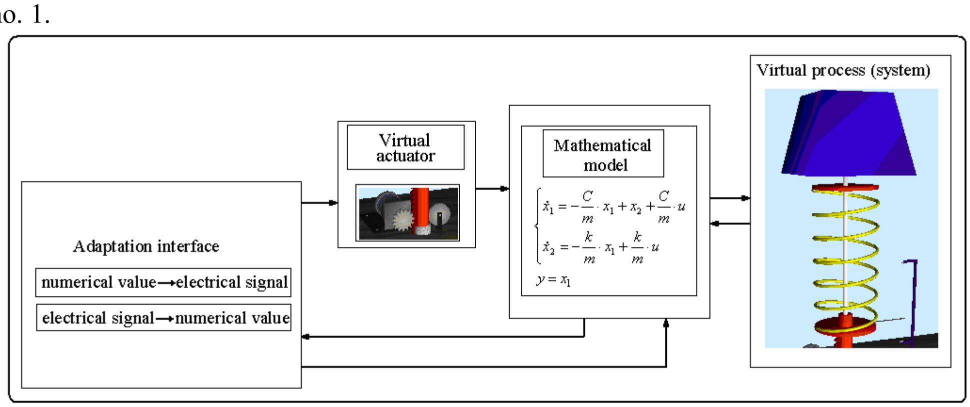

Figure 1 The structure of a virtual process

Software and hardware components of the process are shown below:

The virtual process corresponding to a real system allows observation of the system components behaviour during analysis. Besides standard components the system also contains limiters and transducers. Also, the virtual system allows observation from different angles and distances. In this way it is possible to watch and observe different system components during the analysis. The system shown above consists of a suspension which contains a spring and a hydraulic shock absorber.

The mathematical model of the process is used as an interface between analysis procedures and the virtual system. The model must catch all important aspects of system dynamics. On the other hand, the mathematical model of the process is subjected to restrictions, taking into consideration that the sizes of the process must belong to well-defined intervals. Numerical integration of the mathematical model is done using Runge-Kutta methods. This method was chosen because it allows nonlinear dynamic system integration using variable integration step.

Virtual actuators are used to illustrate the fact that in order to act on the process you need to convert and amplify the control signal using dedicated components. In many cases the actuators consist of a dynamic system with an associated mathematical model. In the case that the process is much slower than the actuator, the actuator is approximated with a linear transfer characteristic.

The adaptation interface is a hardware component with the following characteristics:

- It converts the control signals received from the process computer, from electrical values to numerical values used as inputs in the mathematical model;
- It converts the mathematical model numerical outputs to electrical signals.

This interface creates a perfect compatibility between a real system and a virtual system from the user's point of view. The control signals used for the virtual actuators are similar to those used with real actuators. In this way, in order to analyse and control the virtual system any hardware configuration can be used: PC with data acquisition card, microcontroller, PLC etc.

3. Mathematical modelling of the dynamical components of a virtual process

For a better understanding of the process, an accurate modelling of all dynamical components of a virtual process and actuators is necessary (Conninx et all, 2006). In this paper, a mathematical model of a car's suspension and also of the actuators is presented.

Suspension Modelling

Oscillation analysis of car's suspension in vertical plan represents one of the most complicated problems of the car's dynamics. The complexity derives from the coupling elements and nonlinearities of the car's suspension. In virtual reality the simulation of road humps is made with the help of an actuator (DC motor or servomotor).

The model used to study the suspension's behaviour on different road humps is presented in figure no.2. Car's suspension is made with one elastic and one hydraulic damper defined by k and C constants. The car with constant weight m, during the movement on the road, encounters a hump of height u which causes a displacing y of the car's body on vertical.

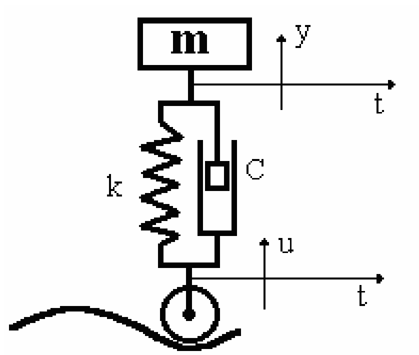

Figure 2 Suspension model

In this case, the equation of the vertical motion uses D'Alembert principle:

$$m\ddot{y} + k(y-u) + C(\dot{y} - \dot{u}) = 0 \qquad (1)$$

or

$$m\ddot{y} + k\cdot y + C\cdot\dot{y} = C\cdot\dot{u} + k\cdot u \qquad (2)$$

where :

m – the body weight;

k – the elastic damper constant;

C – the hydraulic damper constant;

Because equation (2) contains 2-nd order derivative, in order to integrate it must be brought it to a input-state-output form. After a series of transformations the following set of equations is obtained:

$$\begin{cases} \dot{x}_1 = -\dfrac{C}{m}\cdot x_1 + x_2 + \dfrac{C}{m}\cdot u \\ \dot{x}_2 = -\dfrac{k}{m}\cdot x_1 + \dfrac{k}{m}\cdot u \end{cases} \qquad (3)$$

$$y = x_1,$$

Where x_1, x_2 represent the state variables, u – the command, y – the output, and m,k, C - the same meaning as in equations (1) and (2).

Actuator modelling

The actuator amplifies the power of the control signal. In many situations actuators are dynamical systems. The most known actuator is the DC motor. If the process is described by time constants greater than the DC motor ones than these are approximated with the help of input-output static characteristic.

In this paper the following types of actuators are used:

- the DC motor;
- the real servomotor;
- the ideal servomotor.

The DC motor has the mathematical model [13] described by the following set of differential equations:

$$\begin{cases} \dot{i} = -\dfrac{R}{L}\cdot i - \dfrac{K_1}{L}\cdot\omega - \dfrac{1}{L}\cdot u \\ \dot{\omega} = \dfrac{K_2}{J}\cdot i - \dfrac{F_a}{J}\cdot\omega - \dfrac{1}{J}\cdot m \end{cases} \qquad (4)$$

where:

ω – the rotor speed [rad/s];

i – the intensity of rotor current [A];

m –the load torque;
R – the rotor resistance [ohmi];
L – the rotor impedance [mH];
F_a – the friction coefficient [N*m/rad/s];
J – the moment of inertia [Kg*m^2]
K_1, K_2 – the DC motor's constructive constants [N*m*s]

The real servomotor is a device that has a linear transfer characteristic but with a finite rise time. This means that the output follows the input, but with a delay. If the input varies, the output will have a linear evolution until it reaches the size of the input (figure no.3).

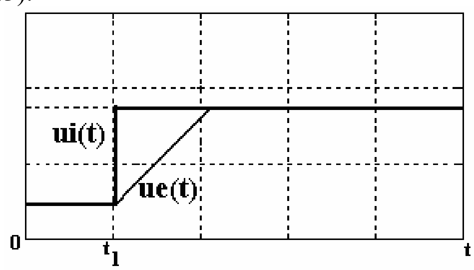

Figure3

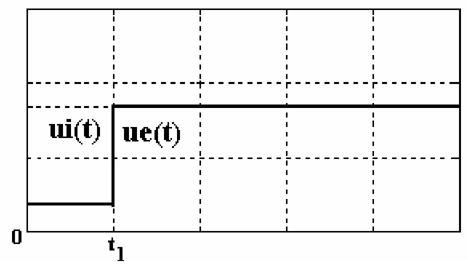

Figure 4

The ideal servomotor is the particular case of the real one, where the rise time is infinite. In this case the output is equal to the input applied to the actuator: ue(t)=ui(t). This ideal servomotor is used because the transfer function of the process can be identified directly from data set obtained from the virtual system.

4. Case study. Frequency analysis of the virtual system – car suspension

In this application the amplitude-frequency and phase-frequency characteristics will be determined. These characteristics will be obtained experimentally using deterministic and periodical signals.

Before starting the experiment it is necessary to obtain some a priori information about:

- the domain in which the input signal frequency must vary;
- number of values in frequency domain for which the transfer locus will be determined;
- the cutting frequency ω_t ($A(\omega)|_{\omega=\omega_t} = 0$);
- the frequency for which $\varphi(\omega) = -180^0$.

The car suspension (the virtual process), figure no 5, will be used in this paragraph in order to determine its frequency characteristics.

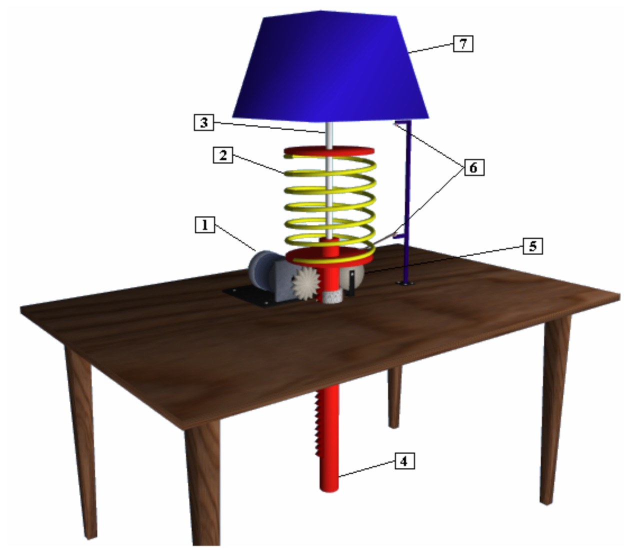

Figure 5 The car suspension: the virtual process

where:

1. actuator – can be DC motor, real or ideal servomotor.
2. damping spring – damping out of oscillation
3. viscous damper
4. motion transmission from the actuator
5. guide element
6. elevating stops
7. mass

Data processing

The methods of automat data processing resulted from conducting the experiment will determine the real and the imaginary part of the transfer locus. Using the nonparametric representation of the system (transfer locus) the amplitude $A(\omega)= |G(j\omega)|$ and the phase $\varphi(\omega)=arg(G(j))$ can be determined.

The function of partial polar correlation [4] defined for [0 T] will be used as the method for determining the transfer locus.

$$R_{yu}(\tau)=\frac{1}{T}\cdot\int_0^T yt)\cdot u(t+\tau)dt \qquad (5)$$

where u*(t)* and $y(t)$ are the virtual system (car suspension) input and output respectively.

If the input signal u(t) is a sinusoidal one, the partial polar correlation function will be: $R_{yu}(\tau)=\frac{1}{T}\cdot\int_0^T A_i\sin[\omega(t+\tau)]\cdot A_e\sin(\omega t+\varphi)dt$ (6)

The real and the imaginary parts will be computed for the following values of the τ :

For τ =0 the equation (6) will be

$$R_{yu}(0) = \frac{A_i^2}{2} \cdot \operatorname{Re} G(j\omega)\,, \tag{7}$$

And for τ =T/4 the equation (6) will be

$$R_{yu}(T/4) = \frac{A_i^2}{2} \cdot \operatorname{Im} G(j\omega)\,. \tag{8}$$

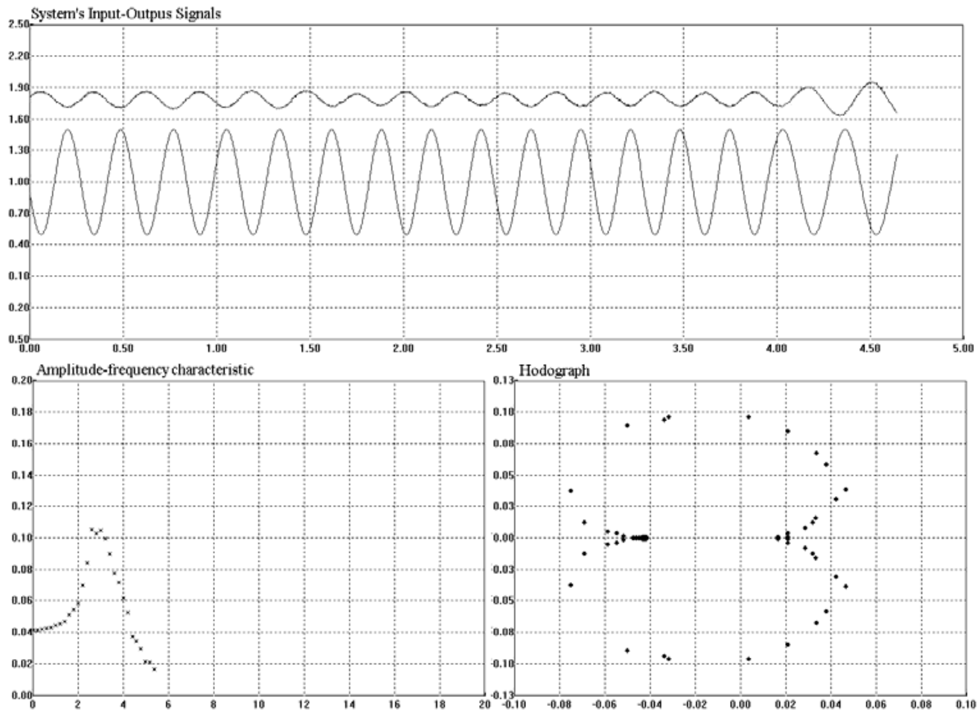

Figure 6 The hodograph and the amplitude-frequency characteristic

<u>System identification</u>

In the following, the steps used for computing the real (equation 7) and imaginary (equation 8) parts of the hodograph will be presented:

- generating the sinusoidal input signal with the frequency chosen from the frequency vector
- computing the output corresponding to the sinusoidal input signal
- using equation (7) the correlation function will be computed in order to obtain the real part and using equation (9) the correlation function will be computed in order to obtain the imaginary part.

The hodograph and the amplitude-frequency characteristic obtained using the educational software for dynamical systems analysis will be presented in figure 6.

5. Conclusions

In this paper a virtual process connected with an embedded computer through an acquisition card was presented. The virtual reality offers many advantages for system analysing and for the control low synthesis. In order to approximate the real process, the models for the car suspension and for the DC motor were also obtained. In the end of the paper a case study is presented. This case study consists in frequency analysis of the car suspension system.

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