VISUALISATION TECHNIQUES FOR 2-DIMENSIONAL SYSTEMS DESIGN

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The past decade has seen an increasing interest from engineers in systems modelled as transfer functions involving two independent variables. Advances have been made in the theoretical understanding of such models and new control design techniques are beginning to emerge. There remains a lack of good CACSD tools allowing easily understood visualisation of 2-dimensional systems for both analysis and compensation purposes. The paper describes prototype tools constructed to give insight into 2-dimensional system by using the type of visualisation environment normally associated with virtual reality. *Copyright ©2000 IFAC*

1. INTRODUCTION

Classical control systems design uses a range of two dimensional graphical tools which give the designer relevant information displayed and easily comprehended in a single view. Examples of such tools include Bode, Nyquist and root locus plots. An experienced designer can immediately infer the dynamic behaviour of the system under different conditions by studying the plots and, further, can assess the impact of different compensators formed by the addition of extra poles and zeros into the overall system. In contrast to this, analogous graphical tools for 2-dimensional systems generally involve 3- (or more) dimensional plots for which a single 2-dimensional view projected on a 2-dimensional graphics screen is likely to prove inadequate. Further, compensation design is not as straightforward as not all 2-dimensional functions can be expressed in terms of linear factors.

This paper describes a prototype computer-aided control system design approach which is based on the visualisation software used in virtual environment work. This approach leads to visualisations which can be easily manipulated so that areas of difficulty are more readily exposed to the user.

2. BACKGROUND

Visualisation tools for 2-dimensional systems need to provide the designer with information about the system's behaviour and how it may be affected by possible control strategies. Both frequency and output responses are of interest and, in both these cases, the information to be displayed is 3-dimensional in nature. Various approaches have been explored and these include 2-dimensional contour maps, (Hu *et al*), 2-dimensional intensity plots (Mesereum *et al*) and 3-dimensional mesh plots (McClellan). Clearly, 2-dimensional representations are less than ideal in that they are unable to provide immediate visualisation of the third dimension which must be inferred from the closeness of the contours in the first case, or intensity of colour in the second. 3-dimensional surface mesh plots with colour mapping provide a better and more natural visualisation. However, when the object is viewed from one point only, the viewer is unable to determine any information hidden from sight. Software such as Matlab allows viewpoint changes, but there is a significant time taken to recalculate and redraw, possibly deterring the user from multiple viewpoint changes and thus increasing the possibility that problem features remain unnoticed.

The approach taken here is to extract the full usage of 3-dimensional displays by employing the powerful 3-dimensional, graphical and visualisation techniques used in the construction of virtual environments (Warwick *et al,1993*). The design tools are built in the form of applications using graphical user interfaces (GUIs) for interaction and virtual environment technology for the displays. Hardware is a Silicon Graphics Indigo2 with 128 Mbyte memory, a 150MHz R4400 processor and R4000 floating point co-processor. The GUI is 'Builder Accessory V4'.

3. GENERAL USER INTERFACE

All the applications were based on the same overall approach. Each tool offers the user a screen comprising panels for data entry, environment controls, environment information and one or more visualisation windows. Transfer functions are entered as two coefficient matrices, one representing the numerator and one the denominator. Element i,j in such a matrix is the coefficient of z_1^{i-1}, z_2^{j-1}. Each object in a visualisation window is displayed with fixed material properties, such as colour, and is illuminated by a light directly above it. The environmental control panel allows the object in a window to be position via three sliders corresponding to the three axes and rotated via three dials, each dial corresponding to rotation about an individual axis. Experimentation suggested that rotation about each axis provided the most intuitive way for a user to manipulate the visualised object. The environmental control panel may also include a slider allowing a horizontal grid to be moved up and down the visualised object. This makes it possible to display information in a particular plane, making it relatively straightforward, for example, to read signal amplitude at a specific point and/or time. The environment information panel displays data from the grid.

The basic system described was used to provide applications for both output and frequency (gain and phase) responses (Taylor et al, 1998). In the case of 2-dimensional systems, the frequency response is a much more complicated object to visualise than in the 1-dimensional case. Polynomials in two variables cannot necessary be reduced to a product of linear factors as is the case with polynomials in one variable. This means that poles and zeros of 2-dimensional systems are not singularities in 2-dimensional space, but manifolds in 4-dimensional space. Creating a frequency plot from simple basic shapes, as happens in the 1-dimensional case with the Bode plot, thus becomes impractical for all but the simplest systems.

4. COMPENSATOR DESIGN

Classical 1-dimensional compensator design using the Bode plot relies on the fact that both the open loop transfer function and any compensator can be represented in terms of products of linear and quadratic factors with real coefficients. The log scale of the Bode plot means that the open loop transfer function is formed from the addition of very simple shapes corresponding to these factors. The effect of forward path compensation is also easily predicted as additional poles and zeros are simply added in to the gain and phase plots. As indicated above, the situation for 2-dimensional systems is much more complex as, in most cases, the transfer function will not reduce to linear and quadratic factors (even if complex coefficients were acceptable) and it is thus not a straightforward task to assess the compensator required to lead to a particular change in the response. It has been shown however, that even with complex transfer functions which will not factorise, certain simple structures analogous to classical 1-dimensional lead-lag and lead-lag compensators can be used to build up an overall compensation scheme if both the basic system and compensator can be visualised and the latter manipulated in real time. The third application described here allows the creation and visualisation of such a compensator in the frequency domain. The screen retains the same overall design as before, but additional panels are included to allow up to three different compensators to be added. Each compensator takes the general form $(n_{00}+n_{10}s_1+n_{01}s_2+n_{11}s_1s_2)/(d_{00}+d_{10}s_1+d_{01}s_2+d_{11}s_1s_2)$. Choice of coefficients allows this generic compensator to take forms very similar to classical lead-lag or lead-lag compensators. An additional four sliders are available to control compensator coefficients. The slider position corresponds to coloured lines appearing at points on the frequency axis in the virtual environment. These handles correspond to the appropriate break-point of the magnitude frequency response. Moving the slider moves the handle and alters the coefficient in real time. Once the slider is released, the frequency response is automatically update. This interactivity gives the user the facility of generating simple compensation form visual cues. The display area of the screen is able to show the uncompensated system, any one of the compensators or the compensated system. Colour is used to distinguish the individual frequency responses with red, green, blue, yellow and cyan used for the uncompensated system, compensator 1, compensator 2, compensator 3 and the compensated system respectively.

5 CONCLUSIONS AND FURTHER WORK

The results shown demonstrate that by using interactive virtual environment software, an approach to 2-dimensional system design can be developed which is visual, intuitive and analogous to classical 1-dimensional approaches. The issue of compensation is particularly complex and there is a need for further work. One approach being considered is to allow the designer to 'sketch' an appropriate compensator and then to automatically generate the closest compensation function of a given order to this design requirement.

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REFERENCES

Hu, J.V., et al "Design Techniques for Two Dimensional Digital Filters" . *Selected papers in Digital Processing II*. IEEE Press.

Mesereum, R.M., et al, "Two Dimensional Digital Filtering". Selected paper in *Digital Signal Processing II*. IEEE Press.

McClellan, J.H., "The Design of Two Dimensional Digital Filters by Transformations". Selected Papers in *Digital Signal Processing II*. IEEE Press.

Taylor G.E. et al, 1998, "Virtual Environments for 2-Dimensional Control Systems Design". Proc. Control 98, IEE, London.

Warwick, K. et al, 1993, *VirtualReality in Engineering*, IEE London.