Chapter 7

Conclusions and recommendations for further research - Part II

Research into the application of non-linear time domain system identification techniques in general modelling and simulation of dynamic systems, and more specifically implementation into structural response reconstruction, was prompted by a large scale research program surrounding the time domain based QanTiM simulation software package. Structural response reconstruction is the process where actuator drive signals are calculated to force rig responses close to actual measured field responses. Actuator drive signals are found by simulating measured field responses through an inverse dynamic model of the test system. This inverse dynamic model is found by using a dynamic system identification technique. In the case of QanTiM, a linear parametric time domain system identification technique is used.

QanTiM is capable of modelling and subsequently simulating dynamic responses in most structures. It has however occurred that a dynamic structure could not be modelled accurately, resulting in poor simulation results. The limitation of existing linear system identification techniques used within QanTiM was seen as a potential cause of such modelling difficulty, hence this study into non-linear system identification and modelling

As outlined in the introduction, an appropriate non-linear system identification technique was required to be well suited to application in response reconstruction, yet capable of seamless integration with the existing linear techniques. Furthermore a black-box type model which was easy to use, and required minimal structure definition prior to identification was needed to allow implementation within the existing QanTiM software. The NARX model structure, introduced under the guidance of Billings [5] [46][47] proved ideal for these applications. The author subsequently developed and implemented a condensed MIMO NARX model structure for application in response reconstruction and general non-linear dynamic modelling.

7.1. Non-linear system identification: The condensed NARX model formulation

Non-linear system identification is relatively new, and limited practical case study research contributions were available on the subject. Valuable research contributions were made under the guidance of Billings, who presented the NARX model formulation (See references[4] through [8][46] & [47]). The NARX model formulation proved to be well suited to application within time domain system identification and response reconstruction [54]. The author subsequently combined the NARX formulation with the so called 'full order approach' (suggested by Raath [53]). These techniques were adapted and refined, resulting in a condensed NARX model structure, which evolved into a time domain based non-linear system identification 'toolbox' of Matlab functions. The condensed NARX model structure is capable of identifying, modelling and simulating systems with polynomial non-linear behaviour. The condensed NARX functions require minimal structure definition prior to identification. Two parameters need to be specified for each response channel, namely the model order and degree of non-linearity.

7.2. NARX as a general non-linear modelling tool

The NARX model formulation showed notable potential as a general non-linear system identification and modelling tool, capable of accurately and efficiently modelling MISO and MIMO non-linear dynamic systems. Chapter 6 presented four case studies in which the condensed NARX model structure outperformed normal QanTiM modelling techniques. The NARX based techniques proved valuable in modelling the dynamic behaviour of rubber and elastomeric components. Section 6.2 implemented NARX techniques to model stress levels as a function of pneumatic spring pressure in a trailer suspension system. In Section 6.3, the condensed NARX model description was used to identify a model between wheel inputs and ball joint loads for a vehicle front suspension system. This application showed the condensed NARX model structure's ability to model both indeterminate and redundant non-square systems. The NARX techniques were further extended to make use of a split-spectra modelling approach.

Application of the condensed NARX model structure in normal system identification and modelling is summarised below:

- Accurate, and relatively easy, modelling of MISO and MIMO systems with severe polynomial non-linearity.
- Well suited to modelling non-square systems, typically modelling more than one output channels from a single input.
- Potential application would typically be modelling between critical points on a complex dynamically loaded, non-linear structure.
- The NARX formulation excelled if used in a split-spectra modelling technique to accommodate low frequency, high displacement non-linear system behaviour.

7.3. NARX structural response reconstruction

In general, the NARX formulation did not allow successful simulation of systems that could not be simulated using the linear QanTiM software. More important, most test structures encountered did not show enough non-linearity to warrant the extra computational effort required by the NARX technique. Only in a few test systems did the NARX technique render improved simulation results. Examples of successful non-linear response reconstruction using the condensed NARX model structure were presented in Chapter 6. The newly developed NARX techniques allowed accurate simulation of load responses within an elastomeric damper unit. Similarly, NARX accurately simulated required load responses within a vehicle suspension damper. However, after four iterations the results achieved with QanTiM surpassed the non-linear results. NARX outperformed QanTiM in the simulation of operational acceleration responses of a vehicle radiator. The non-linear techniques did however not improve on QanTiM in simulating responses in areas of system resonance.

7.4. Recommendations for further research

NARX system identification techniques were implemented and subsequently applied in structural mechanics. The newly developed, condensed NARX model formulation showed potential as a general, non-linear normal modelling tool with limited potential in dynamic response reconstruction. The case studies presented in Chapter 6 showed the potential of NARX techniques, and prompted recommendations for feature research.

7.4.1. Alternative non-linear modelling capabilities

Test systems for which NARX modelling capabilities did not improve on poor QanTiM simulation results were presented in Table 6.1. These test systems were generally concerned with simulating operational acceleration response. Furthermore, these test systems made use of fixtures that allowed some backlash in the load path. The sensitivity of accelerometer response to system backlash may be the cause of the poor simulations. The NARX technique's polynomial structure is not ideally suited to model backlash response. Dead-band, non-linear system identification and modelling techniques may resolve backlash related problems, and improve simulation results.

7.4.2. Non-square modelling and simulation

The application examples showed potential in modelling and simulation of non-square systems. Section 6.4.1 showed improved simulation results when two remote response transducers were used to calculate the actuator drive signals. Non-square modelling capabilities are not restricted to the condensed NARX model structure. QanTiM techniques can be modified to accommodate non-square systems. Non-square simulation may prove valuable to calculate road simulator drive signals, utilising two remote transducers for each drive channel.

7.4.3. Modified NARX model structures

Split spectra techniques proved valuable to recreate high frequency linear dynamics, together with low frequency non-linear behaviour. The split spectra procedures are however computationally taxing. An alternative approach to split spectra modelling may be the application of the quasi-static modified NARX model formulation presented in Section 5.5.2.