A Classic MATLAB-based Solution of ARGESIM Benchmark C18 'Identification of Non-linear Dynamic Relations'

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Simulator: MATLAB 5.3 with Neural networks toolbox, running on Debian Linux 3.0 was used to solve three tasks: identification with linear model, identification with parallel structure of linear model and ANN, and identification with dynamical ANN.

Model: In identification of dynamical systems, linear methods are often applied first, because of well defined theoretical backgrounds of methods, even though it is clear that the system has non-linear characteristics. Therefore, we started with least-squares identification of discrete-time dynamical model. Non-linear identification requires large data-bases when we have to identify model parameters as well as the non-linearity type. Therefore, several model structures were developed, to reduce the necessary amount of data. One of such structures is parallel combination of linear dynamical model and non-linear statical model (see Figure 1). For non-linear model 2 layered ANN with 7 neurons, having tangens sigmoid function on the first layer and one neuron with linear function on the output was used.

Alternative to parallel structure would be serial structure, however, identification of serial structure is more complex, since both models must be identified in parallel, whereas for parallel structure dynamical model is identified first, and non-linear model is identified with goal to reduce the error of the linear model. Considering the quality of prediction achieved by parallel structure and available data, one must decide whether it is sensible to identify the system with dynamical non-linear structure, such as feed-forward ANN with feedback, or several other dynamical ANN structures, fuzzy models, splines, etc. In our case dynamical feed-forward 2 layered ANN was used with 10 neurons with tangens sigmoid functions on the first layer and one neuron with linear function on the output layer. The output of the network was delayed for one and two samples and fed back to the input layer of the network.

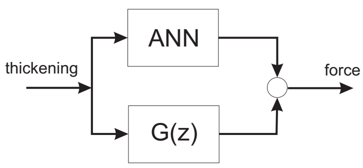

Figure 1. Parallel structure for identification of non-linear systems

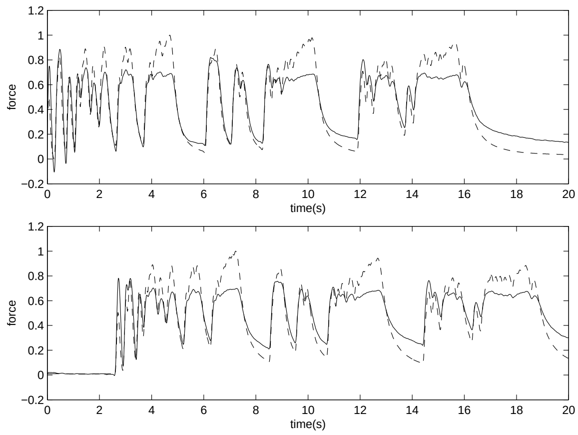

Figure 2. Simulated (solid line) in compare with measured force (dashed line). Training data set above, validation data set below.

A-Task: First identification with linear dynamical model was tried. Matlab *arx* function was used and 2nd order discrete-time model was identified (Eq. 1).

$$G(z) = \frac{0.5289z^2 - 0.5206z}{z^2 - 1.586z^1 + 0.5985} \qquad (1)$$

Model simulation with respect to measured data is presented in Figure 2. As can be seen in Figure 2, linear second order model can describe the general system dynamics, however, the details are not matched. Calculated correlation coefficient of measured and simulated force is 0.95 for training data set and 0.94 for validation set. However, the trend of the error between simulated and measured force is -0.177s^{-1} for training set and -0.02 s^{-1}.

B-Task: The following code in MATLAB was used:

```
E = T-y';
net = ...
   newff(minmax(P),[7,1],{'tansig','purelin'});
net1 = train(net,P,E);
y1 = sim(net1,P);
plot(t,y+y1',t,T,'--')
```

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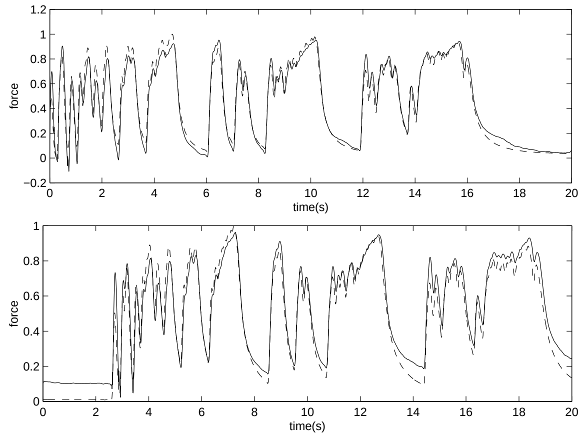

Figure 3. Simulation of the parallel structure of linear dynamical model and the ANN (solid line) in compare with measured force (broken line). Training data set above, validation data set below.

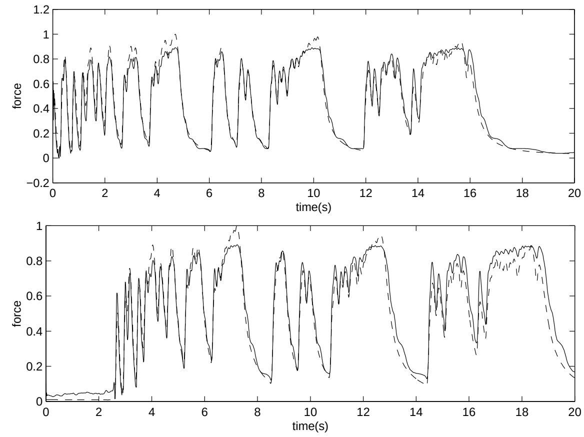

Figure 4. Simulation of the neural network model (solid line) in compare with measured force (broken line). Training data set above, validation data set below.

In the code, E represents the difference between real system's measurements `T` and linear model simulation `y`. Next, a network structure net is created with 7 neurons on the first layer and 1 neuron on the output layer, and is trained according to the system input `P` and target `T`. The network and the linear dynamical model are then simulated in parallel and the result of the hybrid system is shown in Figure 3.

Calculated correlation coefficient increases to 0.98 for training and validation set. However, the trend in error remains -0.151s^{-1} for training set and -0.07 s^{-1} for validation set.

C-Task: The following code was used for the ANN model training:

```
net = ...
    newff([0 1],[10,1],{'tansig','purelin'});
net.layerconnect = [0 1;1 0];
net.layerweights{1,2}.delays = [1,2];
net.inputweights{1,1}.delays = [1,2];
net.trainparam.epochs = 50;
net.trainparam.show = 1;
net2 = train(net,con2seq(P),con2seq(T));
y2 = seq2con(sim(net2,con2seq(P)));
```

The results are shown in figure 4.

Correlation coefficient for model M3 between measured and simulated data for training set is slightly raised (0.99) while it remains the same for validation set (0.98). The problem still remains the trend in error between simulated and measured data. For training set, the trend is -0.155 s^{-1}, and for validation set -0.178 s^{-1}.

Resumé: It can be concluded that relation between muscle belly displacement and muscle force has a non-linear characteristic, since it is not possible to model the details with model M1 while the model M1 is relatively successful in describing the system dynamics. With both non-linear models M2 and M3 it is possible to achieve much better prediction of details as well as system dynamics. However, the problem with trend in error between measured data and simulation remains, regardless of the model used for simulation (M1, M2, or M3). The values of trends in error are relatively independent on the model used for simulation. Thus it can be concluded that not all the information of muscle force is present in the muscle belly thickening signal. In spite of missing information, a high correlation of simulated and measured force can be obtained. Although muscle belly thickening signal can provide relatively good information on muscle force dynamics for frequencies up to 5Hz, it cannot serve as an alternative measurement for absolute muscle force measurements.

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