Building a System-Identified FMU in VDM

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Overview

Introduction

- What is system identification?
- Identification methods

Case Study

- Single water tank example
- System identification in Matlab

Implementation

- System-identified water tank in VDM
- Polynomial model (ARX)

Summary and Future Work

What is System Identification?

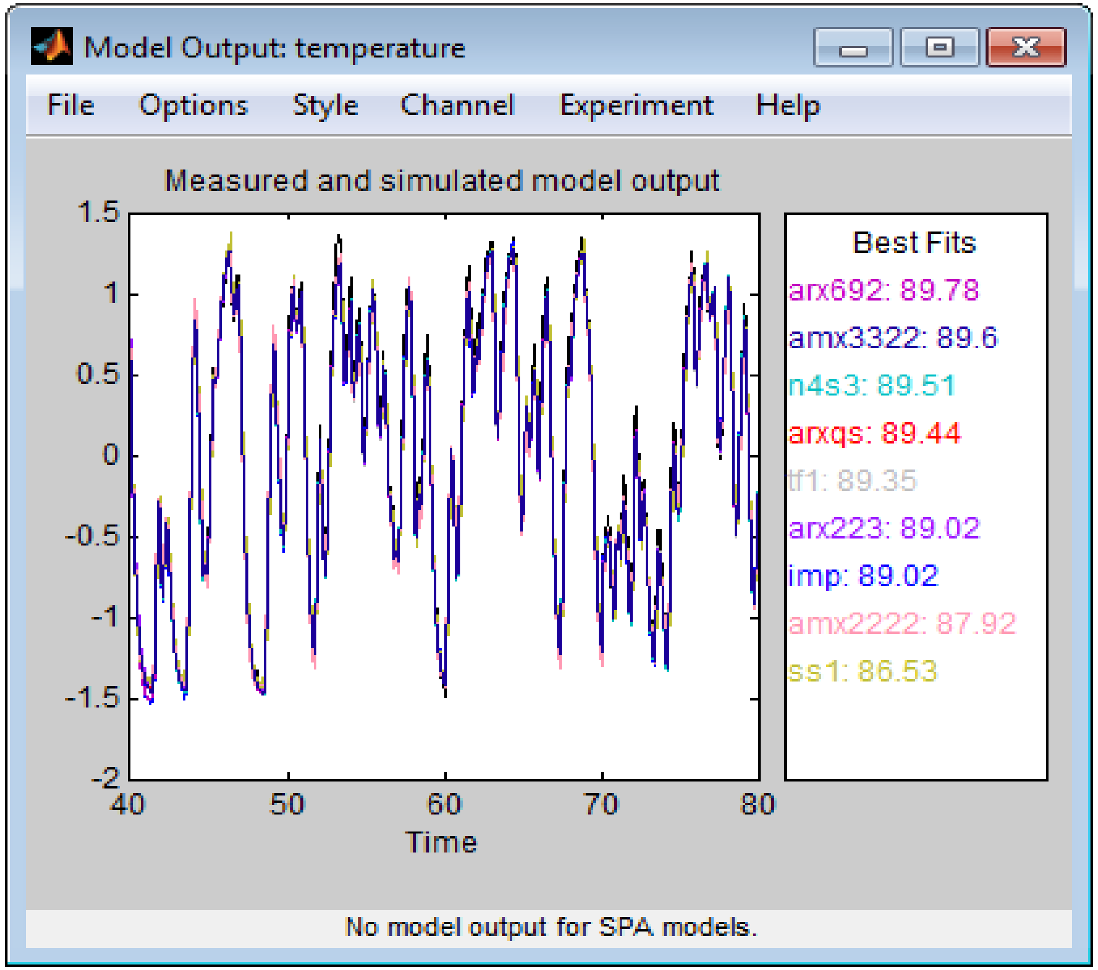
Mathematical model of a dynamic system based on data

- Generate model where it is hard to do from first principles
- Reduce a system to predict only dominant dynamics

1. Measure the input and output signals from your system
   - Can use both time-domain and frequency domain data
2. Select a model structure, e.g.
   - Transfer functions with adjustable poles and zeros
   - State space equations with unknown system matrices
   - Nonlinear parameterized functions
3. Apply estimation method for the adjustable parameters in model
4. Evaluate the model fit

Types

- White box: estimate parameters of a physical model (i.e. calibration?)
- Grey box: estimate parameters for generic model (see above)
- Black box: determine structure and parameters (rarely used)



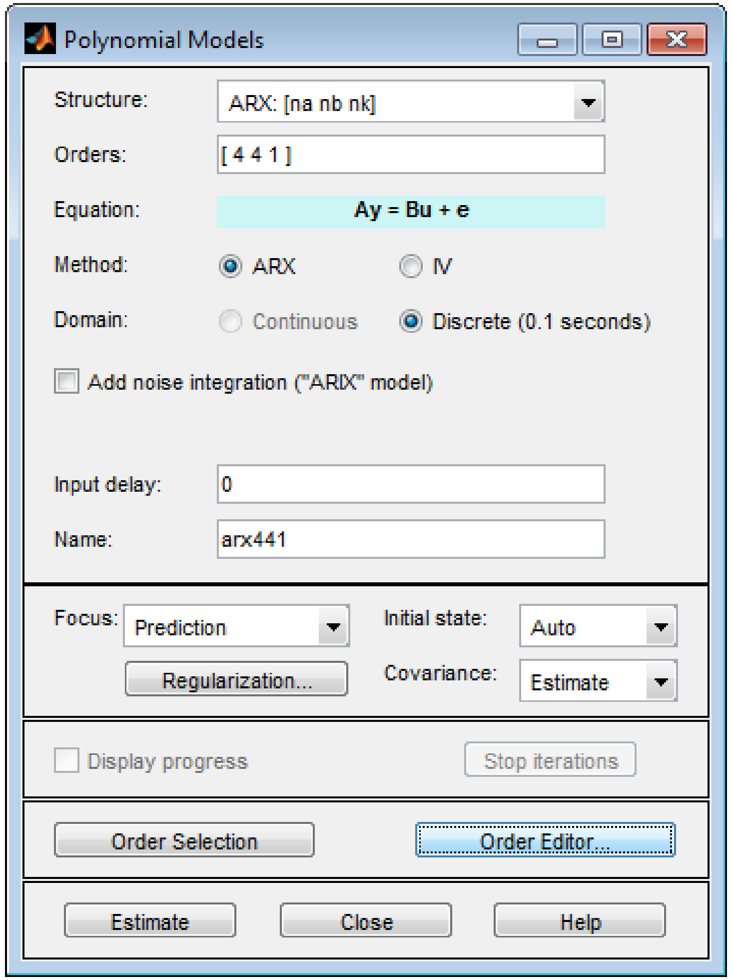
System-Identified model in Matlab and their fit to a validation dataset

Identification Methods

Can be categorised as Linear and Non-linear methods
- System identification for lines systems is well-understood
- Non-linear system identification is an area of active research

Linear time-invariant models
- Polynomial
- State-space
- Transfer functions

Initial study
- Single input, single output
- **ARX** (AutoRegressive eXogenous)
- A polynomial technique



Matlab system identification dialogue

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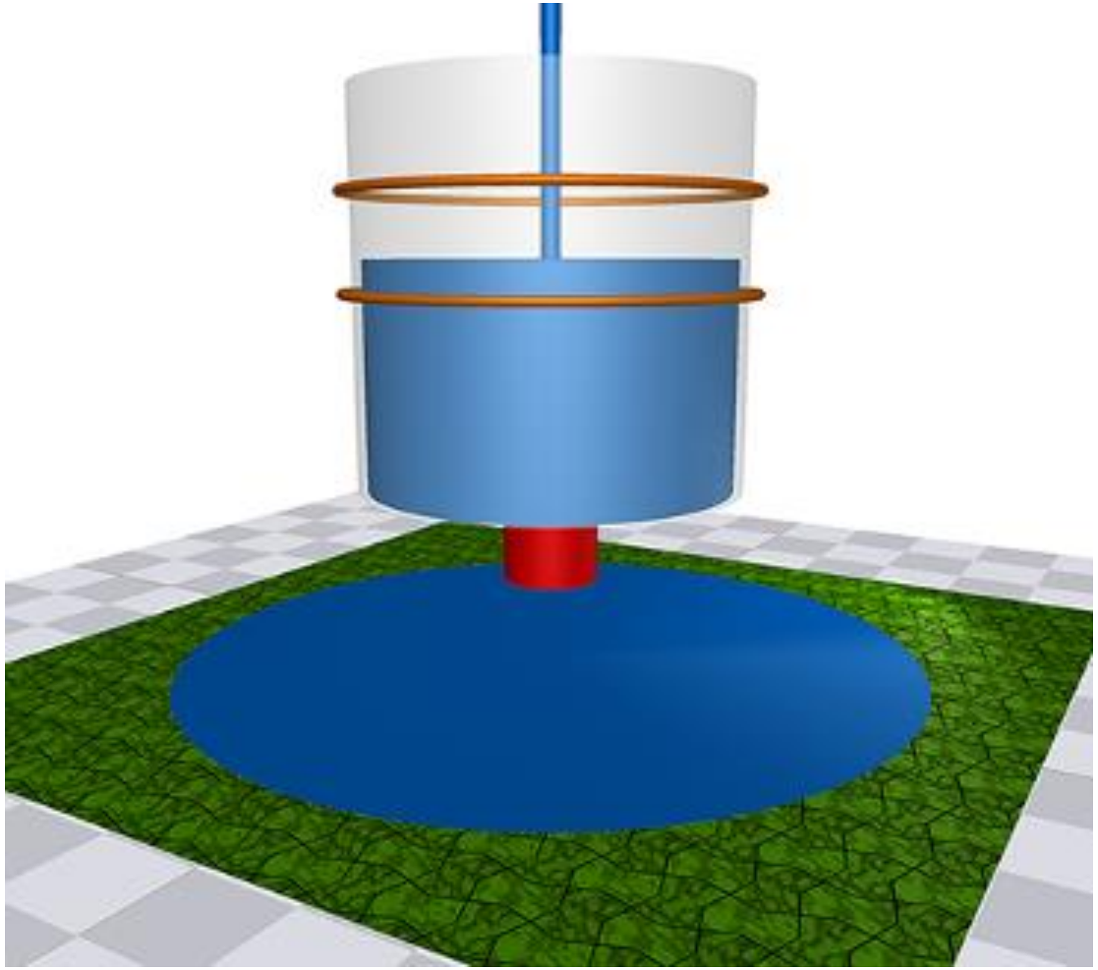
Single Water Tank Example

A simple system
- Water continually fills a tank
- The level is sensed and a valve is actuated
- The controller must keep the level between two marks

Existing multi-model
- Controller in VDM/Overture
- Tank in 20-sim

Dataset
- Output from co-simulation run
- Data from 20-sim tank (valve state, water level)



A visualisation of the single water tank example

System Identification

Data is pre-processed

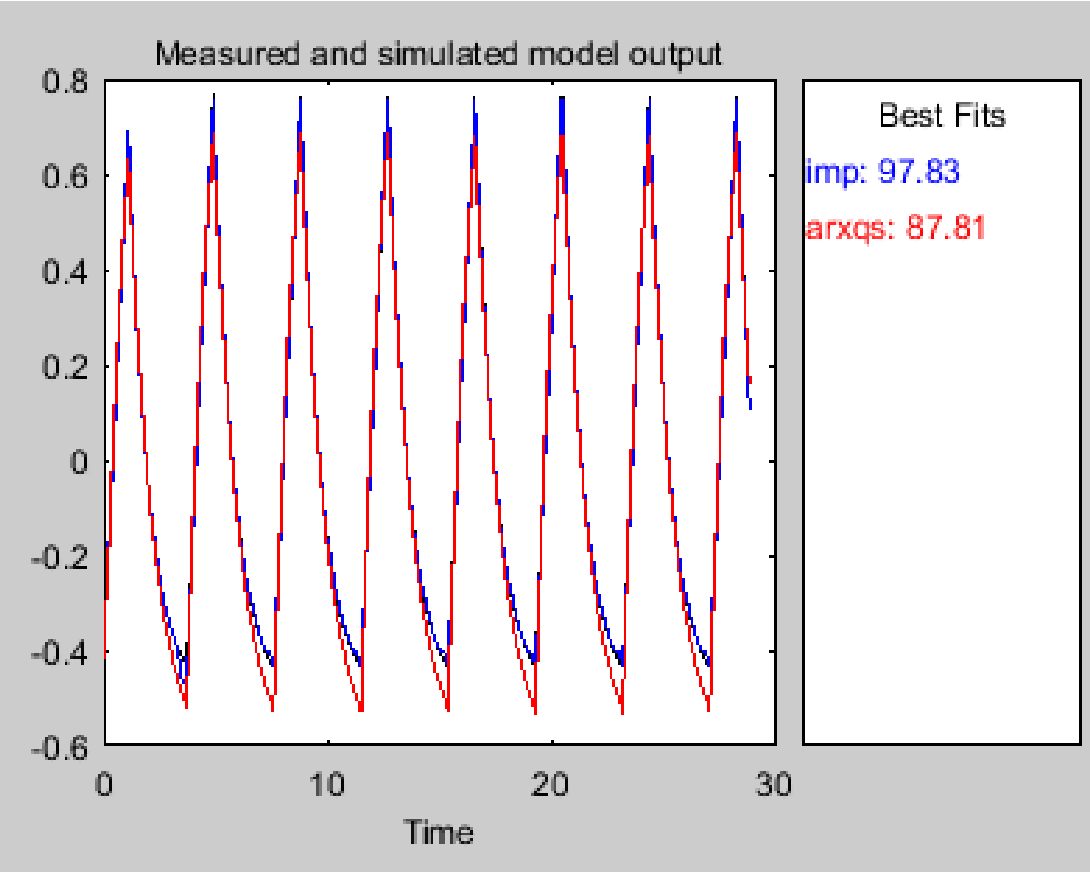
- Data is “de-meaned” so the is zero
- Note negative water level on the right

System Identification Toolbox

- Quickstart option allows comparison of methods
- Shows the fit of various alternatives

ARX fit was selected

- Impulse response was the best fit of the polynomial methods
- ARX was easier to implement



Water level and fit for impulse response (blue) and ARX (red)

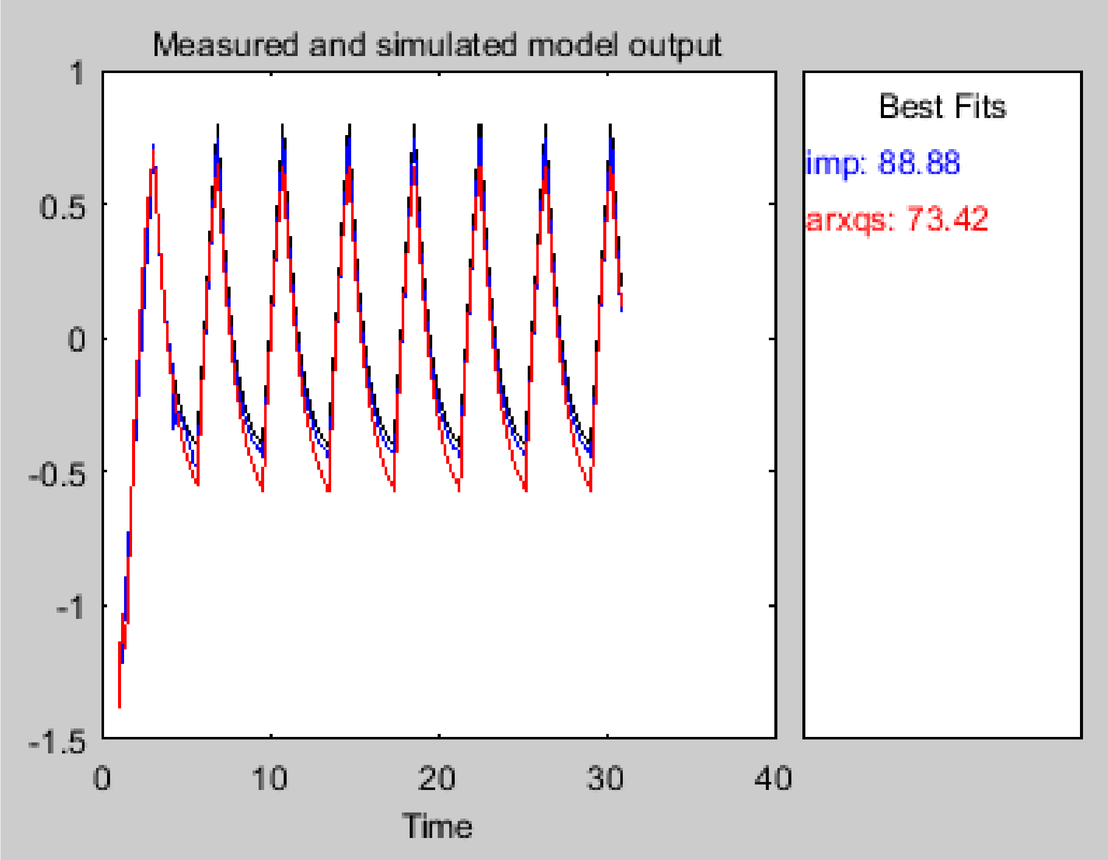
System Identification

Accuracy of fit

- Here the best fit is when the level is between high and low marks
- Accuracy is reduced when the tank is initially empty

Output for VDM

- Toolbox provides coefficients for the selected method
- Here in the form of vectors *A* and *B*



Reduced accuracy of fit when beginning from an empty state

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ARX in VDM-RT

Polynomial model

- Coefficients A and B of length *n*
- Previous output and input multiplied by A and B respectively
- Higher model order results in a longer A and B with more accuracy

$$y(t) + A_1 y(t-1) + \cdots + A_n y(t-n)$$
$$= B_1 u(t-n) + \cdots + B_n u(t)$$

Implementation

- Two for-loops update the output (total)
- Total added to history for next iteration
- Input (u) read for next iteration

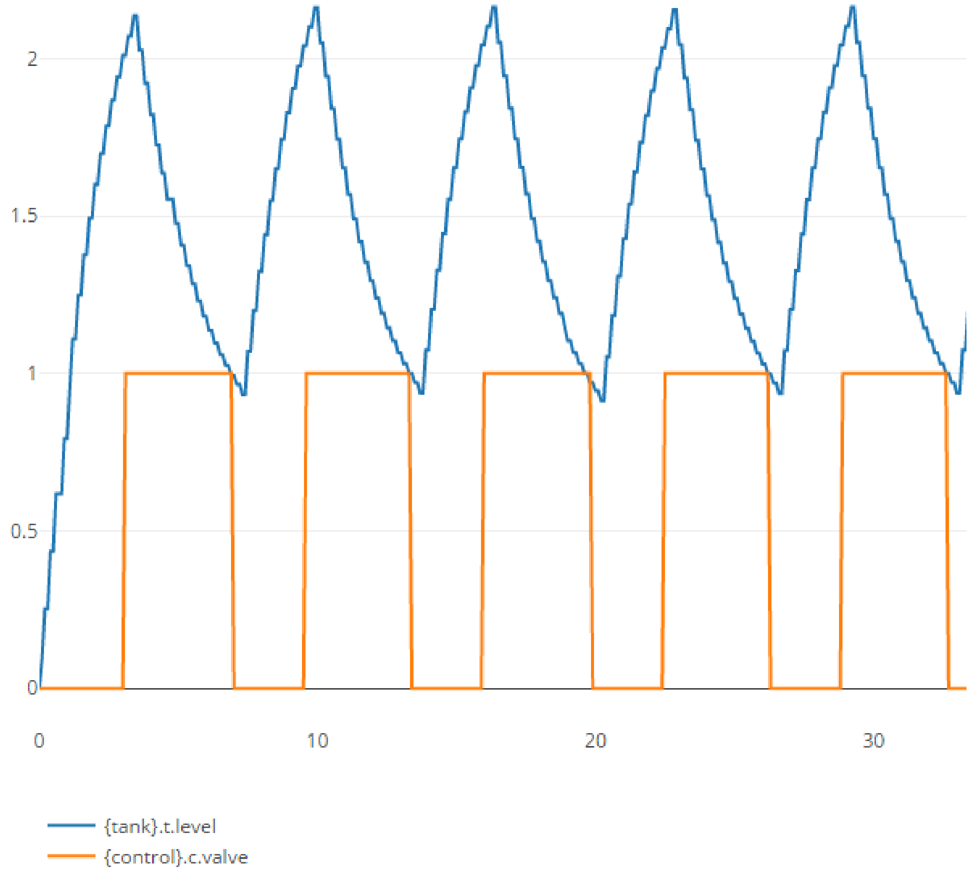
```
dcl total : real := 0;
for i = 1 to nb by 1 do
        total := total + b(i) *
        u(len u - (i - 1));
for j = 1 to na by 1 do
        total := total - a(j) *
        history(len history - (j - 1));

history := tl history ^ [total];

levelActuator.setLevel(total);
u := u ^ [valveSensor.getValve()];
```

Part of the Step() method from the ARX model in VDM-RT

Co-simulation Output

Swap FMU in the multi-model
- Export ARX FMU from Overture
- Replace the 20-sim tank FMU
- All other settings remain the same

Run co-simulation
- Output is an approximation of the original behaviour
- Jagged output due to discretisation
- ARX does not perfectly capture the mix of linear fill (note the curve of the initial level rise) and asymptotic emptying
- Impulse response model might work better in this case



Co-simulation output showing water tank filling and emptying

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Summary and Future Work

Summary

- Applied system identification on data from the water tank
- Implemented a basic ARX model in VDM-RT
- Successfully replaced 20-sim water tank in co-simulation

Future work

- Implement some other models in VDM (e.g. impulse response)
- Automate FMU generation from Matlab output
- Try with real data

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