Model-on-Demand (MoD) Estimation for Behavioral Intervention Optimization

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Abstract

This project explores the use of Model-on-Demand (MoD) estimation to model noisy, nonlinear time series data. Two applications were examined: (1) a continuously-stirred tank reactor (CSTR) and (2) walking behavior from *HeartSteps*, a microrandomized study that aims to encourage physical activity. The CSTR demonstrates that MoD can be applied to noisy, nonlinear data, and the latter shows MoD's effectiveness in more complex systems, accounting for environmental factors. Better models created through MoD will allow researchers to provide more accurate behavioral health interventions.

Model-on-Demand

MoD combines local and global modeling – a local model is estimated at the current working point as needed.

Given a database of observations, obtain a local estimate of the nonlinear ARX structure

$$y(k) = m(\varphi(k)) + e(k), \quad k = 1 \ldots N$$

from the solution of

$$\hat{\beta} = \arg\min_{\beta} \sum_{k=1}^{N} \ell\left(y(k) - \hat{m}(\varphi(k), \beta)\right) \cdot K_h\left(\frac{\|\varphi(k) - \varphi(t)\|_M}{h}\right)$$

We can adjust (1) ARX Model (2) local polynomial order, (3) neighborhood size (goodness of fit criterion)

MoD MATLAB Script

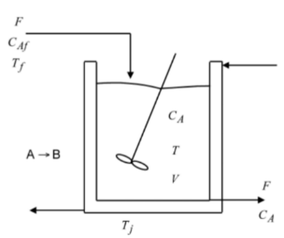
Livescript MoD parameter specifications:

ARX structure	Polynom. Order	Neighborhood Size
ARX [na nb nk]	P (1, 2, 3)	GoF, kmin/kmax

CSTR: Uses data produced by an external script that runs a Simulink model of the CSTR
HeartSteps: Calls a previously-developed simple GUI to extract *HeartSteps* participant data before MoD analysis

Simulated Nonlinear Continuously-Stirred Tank Reactor (CSTR) with Noise

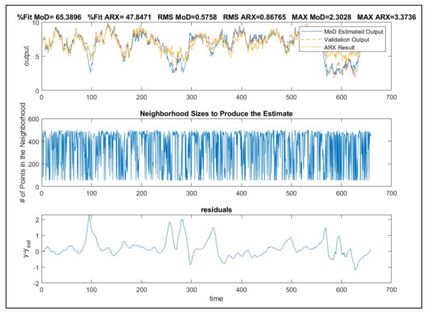
- Introduced process and measurement noise on disturbance inputs (CAF, TF)
- Designed and implemented multi-sinusoidal input signal for jacket temperature



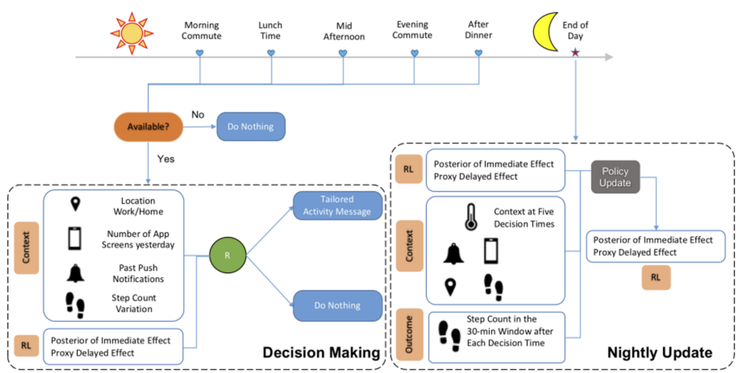
LOW NOISE RESULT (var = 0.001)

MoD Fit %	ARX Fit %
65%	48%

Parameter	Value
ARX	[2 2 1]
GoF	AIC
P	1
kmin/kmax	55/320



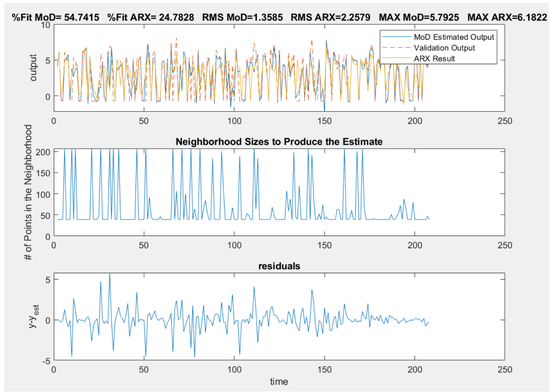
HeartSteps Overview

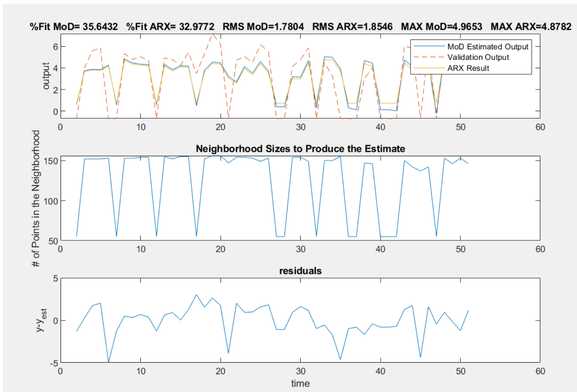


- Applied MoD to HS(v1) participant data (48) taken over 6 weeks.
- Step count through Fitbit, prior to and after walking suggestion

Additional contextual data obtained (four categories): time of day, time of week, location, and weather (18 total inputs)

HeartSteps – Results: Estimation and Prediction





Parameter	Value
ARX	[1 1 0]
GoF	AICN
P	1
kmin/kmax	5/500

MoD Estimation
18 inputs

MoD Fit %	ARX Fit %
55%	25%

Parameter	Value
ARX	[0 1 0]
GoF	GCV
P	1
kmin/kmax	55/500

MoD Prediction
2 inputs

MoD Fit %	ARX Fit %
36%	33%

MoD provides more accurate estimation than ARX.
MoD prediction is marginally better than ARX.

Conclusions

- MoD provides better estimation than ARX for noisy, nonlinear data in which nonlinear effects dominate (CSTR).
- MoD Estimation surpasses ARX for behavioral data – estimation generally improves with more inputs.
- MoD Prediction is comparable to ARX – prediction generally improves with fewer inputs.

Next Steps

- Better understand MoD estimation results
- Better understand MoD estimation versus MoD prediction
  - Add visualization of regressor coverage (important for est/val split data)
  - Improve MoD prediction - add regressor interaction terms
- Evaluate MoD in a new intervention to understand just-in-time states

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