Using ORTO Agents

to Identify Process Model Parameters in Real Time

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Revised 14th January 2022

Abstract

Model identification is the process by which a mathematical description of a dynamical system is built, typically by applying statistical methods to measured system input and output empirical data. Model identification, for example, is a critical step in the building of any model-based control solution. This paper describes how autonomous ORTO agents can be used to estimate model parameters to minimize process model mismatch (PMM), and track system dynamics if they vary in time i.e., those which are non-stationary.

Keywords*: Model Identification; Parameter Estimation; Real-time Optimization; ORTO Agents*

1. Introduction

1.1. Model Identification Overview

Model identification, often referred to as system identification, is the process by which a mathematical description of a dynamical system is built, typically by applying statistical methods to measured system input and output empirical data. Fig. 1 depicts a typical model identification block diagram. The objective of any model identification method is to minimize process model mismatch (PMM). The degree to which this is successful is dependent on the system identification method used, the quality of the input and output data and the mathematical structure of the model chosen. For example, using a linear model structure to model a non-linear process will inherently lead to PMM. Similarly, using quiescent or noisy input and output data may lead to poor model parameter estimation and therefore PMM.

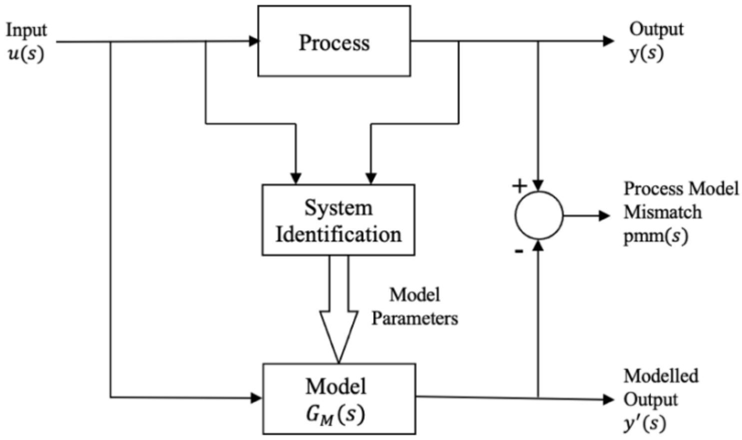

Fig. 1. Input / Output System Identification Block Diagram

Model identification can be performed as a discrete task, offline, using a batch of input / output data. Offline Model identification, for instance, is a critical step in the building of model-based control. Real-time model identification is the updating of model parameters to converge on and then track changes in process dynamics as they vary in time. Such methods are used in adaptive control techniques, for example. A thorough review of system identification techniques is given by *Ljung 1987*.

1.2. ORTO Overview

ORTO (Oram Real-time Optimization) is a proprietary novel model-free real-time optimization approach, marketed by Ortomation Ltd. ORTO offers distinct advantages over traditional RTO technologies. These advantages include greater flexibility, a more intuitive design procedure and straightforward implementation. ORTO also automatically tracks non-stationary (time dependent) optima, e.g., caused by a change in operating philosophy, discrete system modifications, or changes in process dynamics over time. An ORTO scheme is built using independent ORTO agents, each manipulating one system variable. Being model free, ORTO agents have no prior knowledge of the optimization n-dimensional plane. The 'ORTO agent principle' ensures agents learn from each other and work together, to move to and then track the desired optimum value.

ORTO's primary use is to optimize a specific economic, environmental or safety variable within a physical system or process e.g., maximize chemical plant production against quality constraints, minimize fuel used in a power generation plant to meet an energy demand etc. However, being a universal optimization technology, ORTO can be applied to any dynamic optimization problem, as is demonstrated in this paper.

2. Optimization Objective Formulation

To use ORTO agents to deliver real-time model parameter estimation, the model identification task needs to be framed as an optimization problem. Let us assume that a linear second order plus time delay model is to be used:

$$G_M(s) = \frac{y'(s)}{u(s)} = \frac{Ke^{-T_D s}}{C_1 s^2 + C_2 s + 1} \tag{1}$$

A suitable objective function is therefore:

Minimize:

$$pmm(s) = G_P(s)u(s) - \left[\frac{Ke^{-T_D s}}{C_1 s^2 + C_2 s + 1}\right] u(s) \tag{2}$$

By adjusting model parameters K, T_D, C_1 & C_2.

Subject to:

$$0 \le K \le K_h \tag{3}$$

$$0 \le T_D \le T_{D_h} \tag{4}$$

$$0 \le C_1 \le C_{1_h} \tag{5}$$

$$0 \le C_2 \le C_{2_h} \tag{6}$$

To summarize, the process dynamics, $G_P(s)$, are unknown, $u(s)$ is the input signal, $pmm(S)$ is a measured signal and the upper parameter constraint limits K_h, T_{D_h}, C_{1_h} and $C_{2_h}$are user defined.

3. Process Dynamics and Preliminary Modelling

For testing purposes, let us assume the process dynamics, unknown to the ORTO scheme, are linear and described as follows:

$$G_P(s) = \frac{y(s)}{u(s)} = \frac{1.3e^{-20s}}{200s^2+10s+1} \tag{7}$$

Let us also assume that some preliminary offline model identification has given the following first order plus time delay description of the process:

$$G_M(s)|_{init} = \frac{y'(s)}{u(s)} = \frac{0.9e^{-15s}}{15s+1} \tag{8}$$

The extent of the PMM is apparent when both the model and real process are subjected to unit step input, as shown in Fig 2.

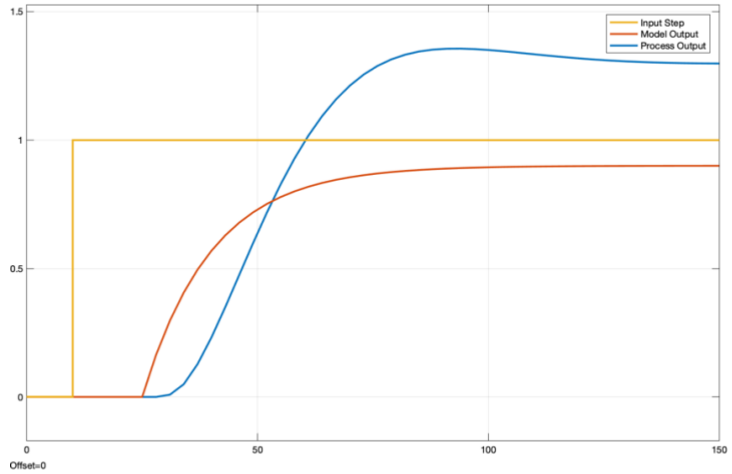

Fig. 2. Process and Model Unit Step Responses

As detailed in the objective function [1] to [6], four model parameters are to be adjusted. Thus, for this specific model structure, four ORTO agents are required. Their collective objective is to minimize the PMM error signal. Comparing [1] with [8], the initial conditions for the separate agents manipulating K, T_D, C_1, and C_2 are 0.9, 15, 0 and 15 respectively.

4. ORTO Scheme Implementation

Appendix A describes the methodology for designing a typical process or system ORTO optimization scheme, however, the outlined steps are still valid for this unorthodox application. The manipulated variables (MVs) and optimization variable (OV) are defined within the objective function and there are no external constraint variables (CVs) or wild variables (WVs) to consider. A suitable parameter estimation scheme is easily built in Matlab / Simulink, based on the framework depicted in Fig. 1. Fig 3 shows the scheme layout to be used for testing purposes. The four required ORTO agents are contained in the 'ORTO Identifier' block.

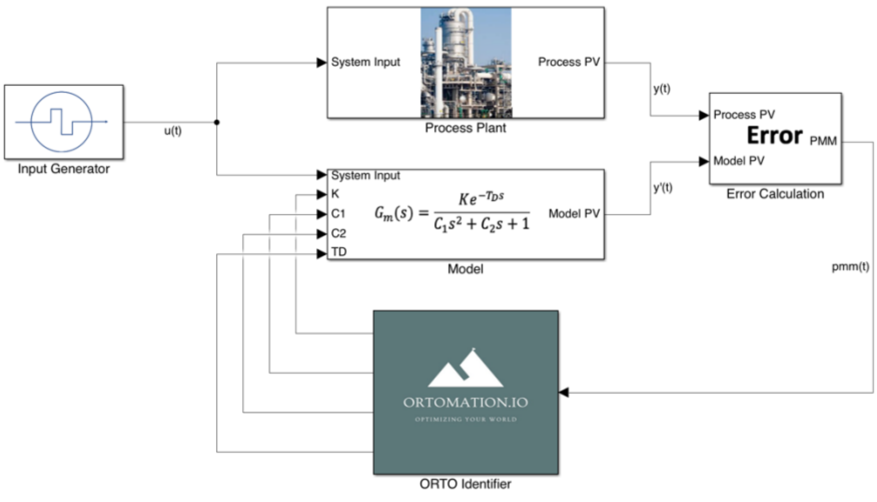

Fig. 3. ORTO Scheme - Simulink Block Diagram

The four ORTO agents required, one for each MV (K, T_D, C_1, and C_2) are contained in the 'ORTO Identifier' block, as shown in Fig 4.

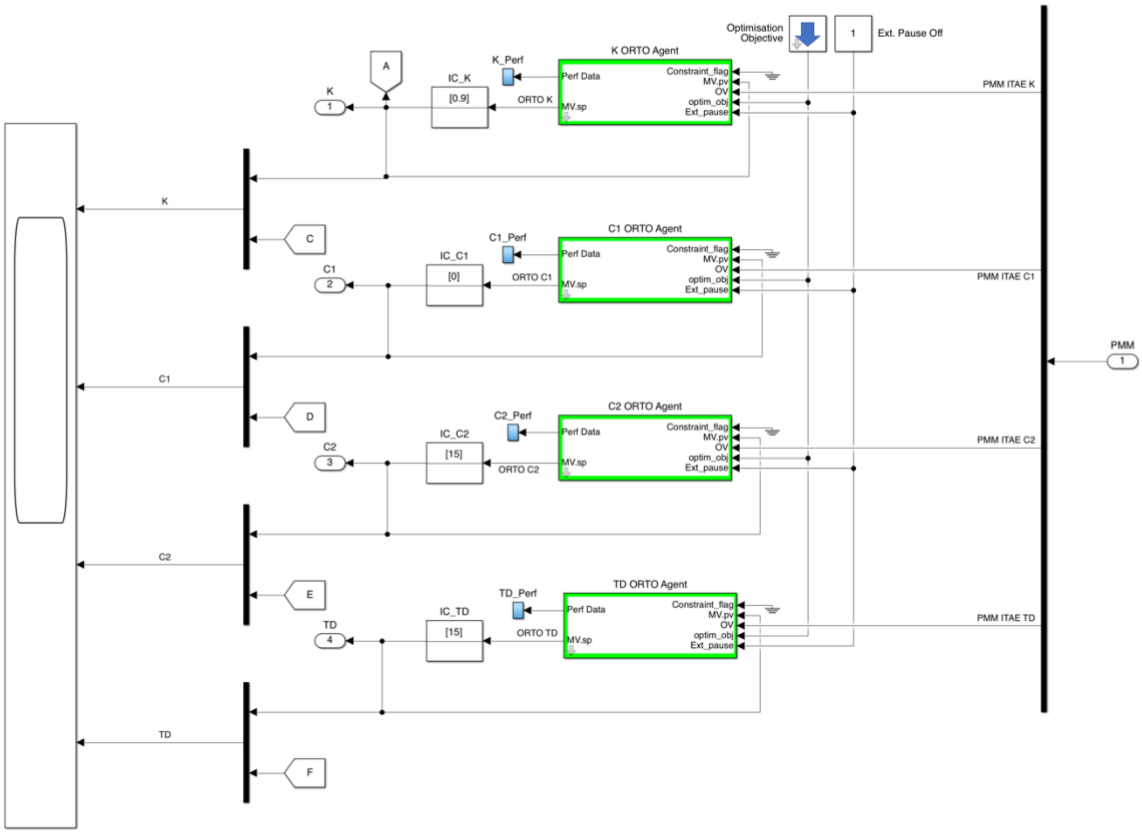

Fig. 4. Simulink ORTO Identifier Block

As can be seen from Fig. 3, both the process and model are perturbed by the same input signal. For the purposes of testing, a simple square wave of magnitude 1.0 and period 100s is to be used. A period of 100s is chosen to ensure process dynamics are sufficiently captured within an input cycle. Each agent reads an accumulated PMM value, calculated at the end of a ΔT_s period, defined as follows:

$$pmm(\Delta T_s) = \frac{\int_0^{T_s} |y(t) - y'(t)| dt}{\int_0^{T_s} |u(t)| dt} \tag{9}$$

Where T_s is the sample time of the respective agent. Dividing by the integral of the input signal, over the sample period, ensures $pmm(\Delta T_s)$ is normalized i.e., compensated for varying input signal magnitudes across the sample times. The 'Error Calculation' block, shown in Fig. 3, computes $pmm(t)$ for each agent.

To reiterate, the ORTO agents are autonomous and have no prior knowledge of the process dynamics [7]. They must work together to navigate and find the set of model parameters which minimize the PMM.

5. ORTO Agent Configuration

The chosen set-up parameters of each ORTO agent are detailed in Table 1.

ORTO Agent 1 (K)	Optimization Objective	Minimize
	OV Engineering Range	[600 0]
	MV Engineering Range	[3 0]
	Sample Time (Secs)	1200
	Max. Move Size	0.06
	MV Upper and Lower Constraint Bounds	[3 0]
	Initial Push Direction?	+ve

ORTO Agent 2 (C_1)	Optimization Objective	Minimize
	OV Engineering Range	[50 0]
	MV Engineering Range	[500 0]
	Sample Time (Secs)	100
	Max. Move Size	8
	MV Upper and Lower Constraint Bounds	[500 0]
	Initial Push Direction?	+ve
ORTO Agent 3 (C_2)	Optimization Objective	Minimize
	OV Engineering Range	[100 0]
	MV Engineering Range	[50 0]
	Sample Time (Secs)	200
	Max. Move Size	1
	MV Upper and Lower Constraint Bounds	[50 0]
	Initial Push Direction?	-ve
ORTO Agent 4 (T_D)	Optimization Objective	Minimize
	OV Engineering Range	[200 0]
	MV Engineering Range	[100 0]
	Sample Time (Secs)	400
	Max. Move Size	2
	MV Upper and Lower Constraint Bounds	[100 0]
	Initial Push Direction?	Unsure

Table 1. ORTO Agent Configuration

The rationale for the settings is as follows:

- **Optimization Objective:** PMM is to be minimized so is set to 'minimize' for all agents.
- **OV Engineering Range:** The optimization Variable (OV) is the $pmm(t)$ signal, which we want to be driven to zero. Thus, the lower range limit is set to zero. Only a rough high level range value is needed. Given a simple square wave of magnitude 1.0 and period 100s is to be used, the high range value is is set to 100*T_s/2.
- **MV Engineering Range:** The manipulated variables (MVs) are the model parameters. Sensible ranges are set based on preliminary modelling results.
- **Sample Times:** Each ORTO agent is set with a different sample time, equal or greater than the period of the input signal. Model parameters which are deemed to have less impact on PMM, when adjusted, are set with smaller sample times, i.e., they will update more often, relative to those that have a greater impact.
- **Max Move Size:** The maximum move of each respective model parameter, across a sample time, is set to 1/50 of the MV span.
- **MV Upper and Lower Constraint Bounds:** Set equal to MV range value i.e., ORTO agents are free to move their respective model parameter across the specified parameter range.
- **Initial Push Direction:** Set to the 'best guess' of where optimum value may reside.

Appendix B provides a deeper overview of how ORTO agent configuration parameters should be set.

6. Simulation Analysis

To demonstrate ORTO performance, four case studies are now presented. For each case, the objective is for the ORTO agents to converge onto and then track their respective true process parameters.

6.1. Case 1: Model Parameter Estimation – Stationary Process Dynamics

For the first test case, the process dynamics are kept fixed, and as described by [7]. The ORTO agents must converge on the true process parameters, having initial conditions described in [8]. The simulation run time is set to 1 day.

As can be seen from Fig. 5, the four ORTO agents drive their respective model parameters onto the true process values within 12 hours. Increasing the max move sizes and / or sample times of each ORTO agent reduces convergence time. For example, doubling the maximum move sizes, halves the convergence time, however, there is a trade-off; movement around the true value, when reached, increases.

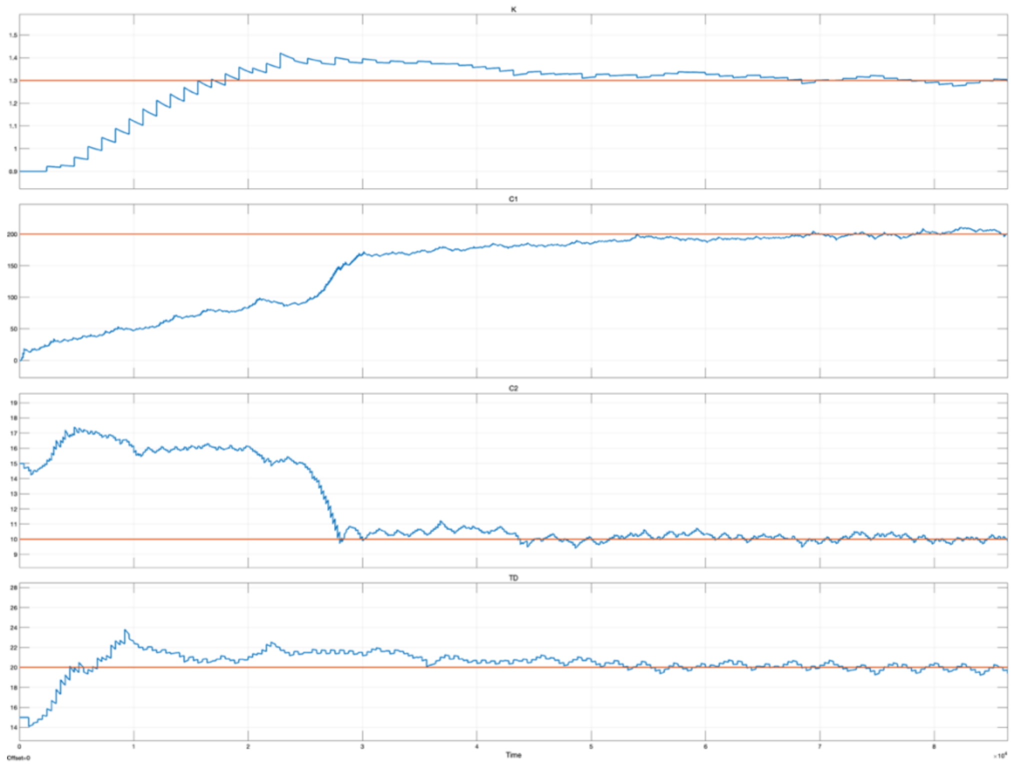

Fig. 5. Case 1. Parameter Estimation Paths (Red – True Parameter Value / Blue – ORTO Modelled Parameter). Simulation time 24 hours.

6.2. Case 2: Model Parameter Estimation – Discrete Change in Process Dynamics

Case 1 conditions are now repeated but with a 50% step change in process gain made after 24 hours.

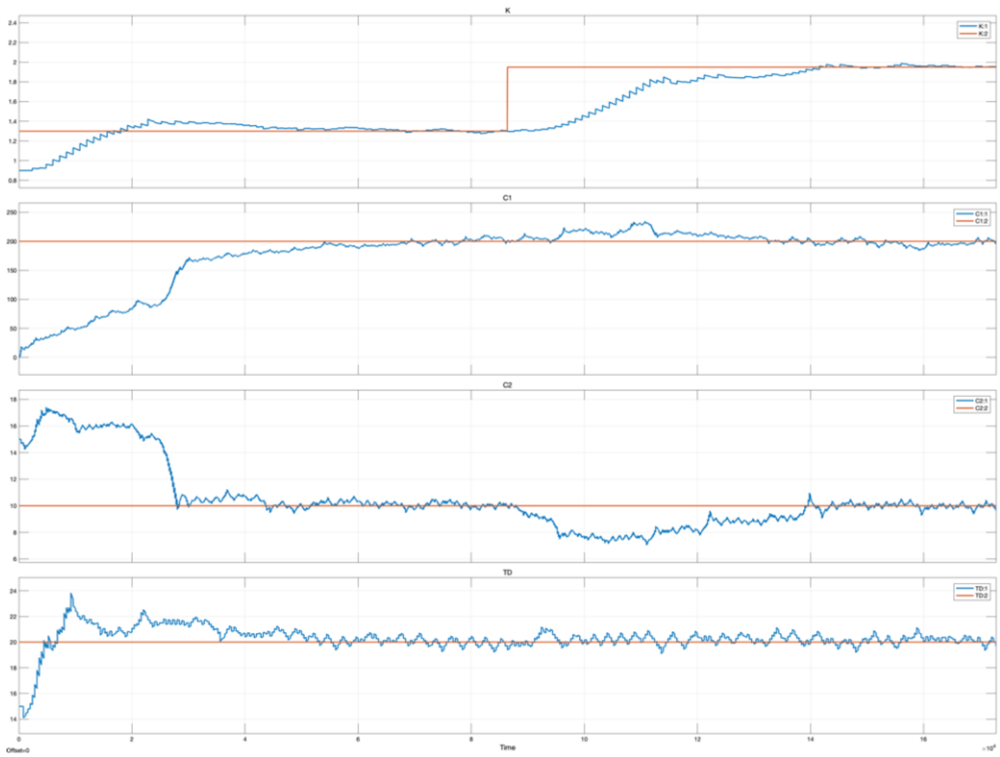

Fig. 6. Case 2. Parameter Estimation Paths (Red – True Parameter Value / Blue – ORTO Modelled Parameter). Simulation time 2 days.

As detailed in Fig 6., the change in process gain creates a disturbance, most notably on the K and C_2 ORTO agents. However, they quickly readjust to reconverge on the true process dynamics.

6.3. Case 3: Model Parameter Estimation – Continuous Change in Process Dynamics

ORTO performance is now tested with process dynamics varying slowly and continuously in real-time. Each parameter is varied sinusoidally with an amplitude of 20% of the initial value. The applied sinusoids are given different frequencies and phase shifts. The ORTO agent maximum move sizes are doubled to help with tracking their respective process parameters.

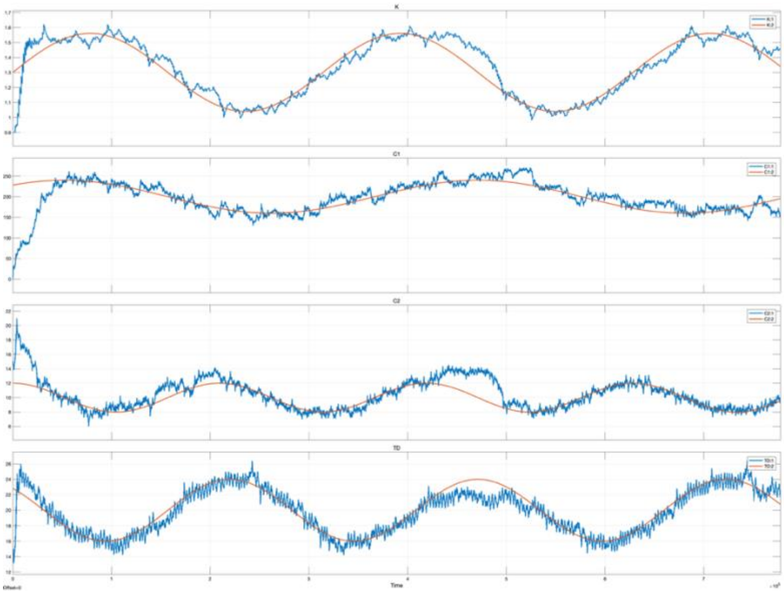

Fig. 7. Case 3. Parameter Estimation Paths (Red – True Parameter Value / Blue – ORTO Modelled Parameter). Simulation time 9 days.

As shown in Fig 7. each ORTO agent adjusts its respective model parameter to track its corresponding process parameter value. The ability for ORTO to converge and then track non-stationary process dynamics over time is thus demonstrated.

6.4. Case 4: Model Parameter Estimation – Continuous Change in Process Dynamics with Process Noise

Finally, case 3 is repeated, but with a random measurement noise signal of amplitude +/-0.1 superimposed on the process output value, y(t). This obviously acts to mask the true process response to the +/-1.0 amplitude square wave input.

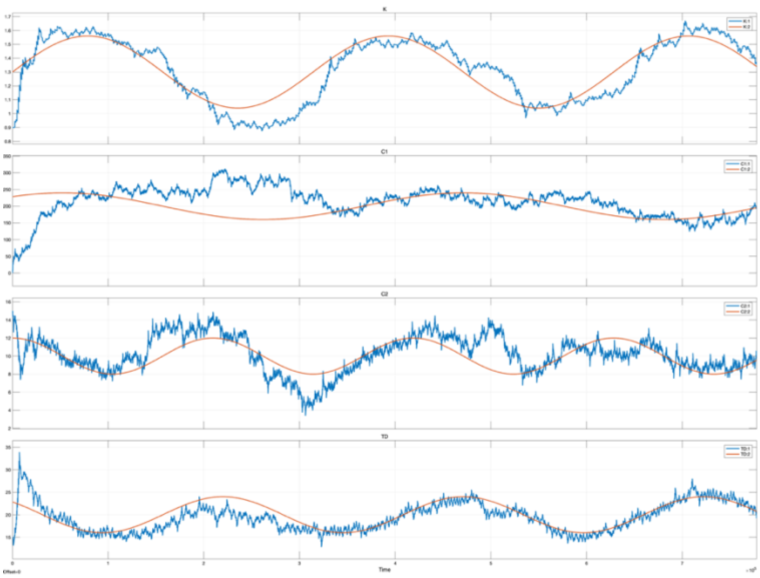

Fig. 8. Case 4. Parameter Estimation Paths (Red – True Parameter Value / Blue – ORTO Modelled Parameter). Simulation time 9 days.

As expected, and shown in Fig.8, parameter tracking is impaired, but none-the-less, the ORTO agents still perform reasonably well.

7. Conclusions and Further Work

Discrete changes in process dynamics may occur due to an operator action or abrupt change in equipment operation. Continuous changes in dynamics may occur due to fouling or degradation of process equipment. Any technique to estimate model parameters in real-time must therefore be able to quickly detect and track such changes. The various test cases were designed to explore ORTO's ability to deal with such situations. When faced with fixed process dynamics, process dynamics which vary as a function of time and when the process output signal is affected by appreciable noise, convergence and tracking performance was successfully maintained.

The test cases presented, using matched process and model structures, allowed the PMM to be driven to zero. Further tests are needed to explore ORTO performance when model identification is applied to non-linear processes and secondly, parameter estimation of non-linear models.

References

Ljung, L., 1987 "System Identification, Theory for the User"

Appendix A. ORTO Scheme General Design Methodology

The procedure to design and build an ORTO scheme, for any given process or system, is as follows:

Step 1: Review business objectives. Identify the key commercial, environmental or safety variable to be optimized (OV).

Step 2: Identify all manipulated variables (MVs) which have an influence on the optimization objective and define the range within which an ORTO agent can safely move them within. The number of MVs identified equals the number of ORTO agents required.

Step 3: Identify any wild 'feed-through' variables (WVs) which directly impact the optimization variable, irrespective of MV action. Modify the OV to take account of the WVs accordingly.

Step 4: Identify any external constraint variables (CVs) that the optimization must respect e.g., product quality variables.

Step 5: Implement each ORTO agent, with outputs cascaded to each respective MV and with OV, MV readback and CV logic inputs configured.

Step 6: Configure each ORTO agent by setting the parameters, as listed and described in Appendix B.

Step 7: Switch each ORTO agent on, in turn, monitoring OV improvements. Adjust maximum move sizes and search space, as confidence grows in optimization performance. Remove any ORTO agents making a negligible contribution. Add further ORTO agents as additional MVs are identified.

Appendix B. ORTO Agent Configuration Parameters

Optimization Objective	Set to 'Maximize' or 'Minimize'. All ORTO agents must have the same optimization objective within an optimization scheme.
OV Engineering Range (EU)	Knowing the OV and MV ranges helps ORTO to calibrate its MV moves.
MV Engineering Range (EU)	
Sample Time (Secs)	Set as a function of system dynamics. Combined with maximum move size, sets the speed of optimization.
Max. Move Size (EU)	The maximum acceptable net move across the defined sample time. Setting maximum move size too low will slow down optimization. Setting it too high may cause excessive movement of MV at around the optimum value.
MV Hi-Lo Constraint Bounds (EU)	The bounds within which the MV can be moved.
Initial Push Direction	Set to 'Positive', 'Negative' or 'Not Sure'. Direction is a function of the initial condition i.e., starting point.