2017 40TH INTERNATIONAL CONFERENCE ON
TELECOMMUNICATIONS AND SIGNAL PROCESSING

MULTI-LOOP MODEL REFERENCE ADAPTIVE CONTROL OF FRACTIONAL-ORDER PID CONTROL SYSTEMS

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TALK OUTLINE

- Motivation and problem statement
- Control system structure
- Methodology: MRAC approach for FO systems
- Simulation Study
- Conclusions

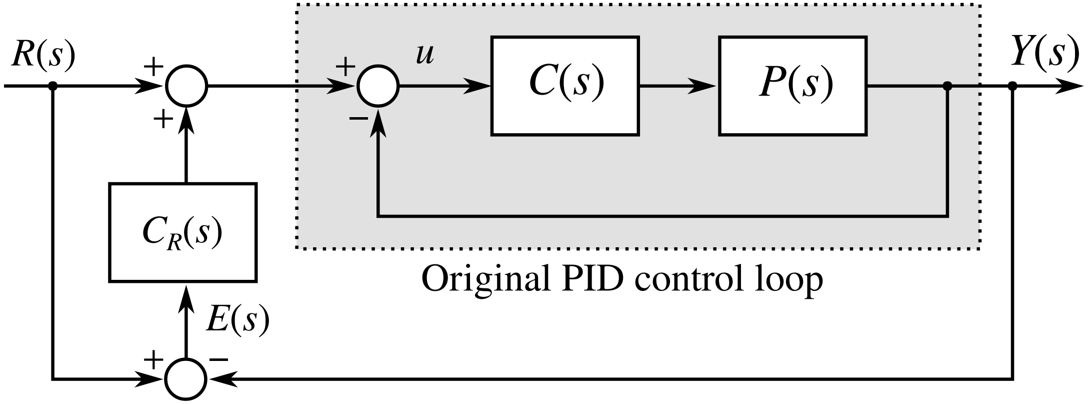
MOTIVATION AND PROBLEM STATEMENT

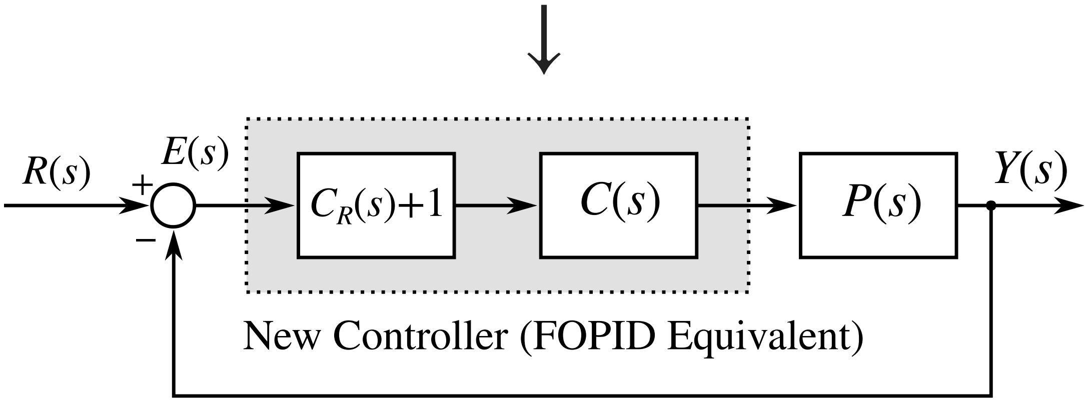
- Model Reference Adaptive Control (MRAC) method based on the MIT rule is applied to closed loop FO control systems.
- The control systems may thus gain adaptation capability.
- The system contains two loops, which are: (1) the inner loop for FOPID control of plant, (2) the outer loop for implementation of MIT rule for model reference adaptive control.
- This approach does not modify any parameter of existing closed loop control system, instead it performs input shaping for the closed loop control system.

WHY FRACTIONAL-ORDER CONTROL?

- Although providing adaptation capability, MIT rule does not guarantee control stability in this application.
- Hence, for system stability and improved control performance, we used FOPID control system in inner loop.
- Fractional-order models represent more accurate description of real systems, so fractional-order system modeling is employed to enhance the reference model of multi-loop MRAC-FOPID system.

PRIOR WORK: FOPID RETUNING†



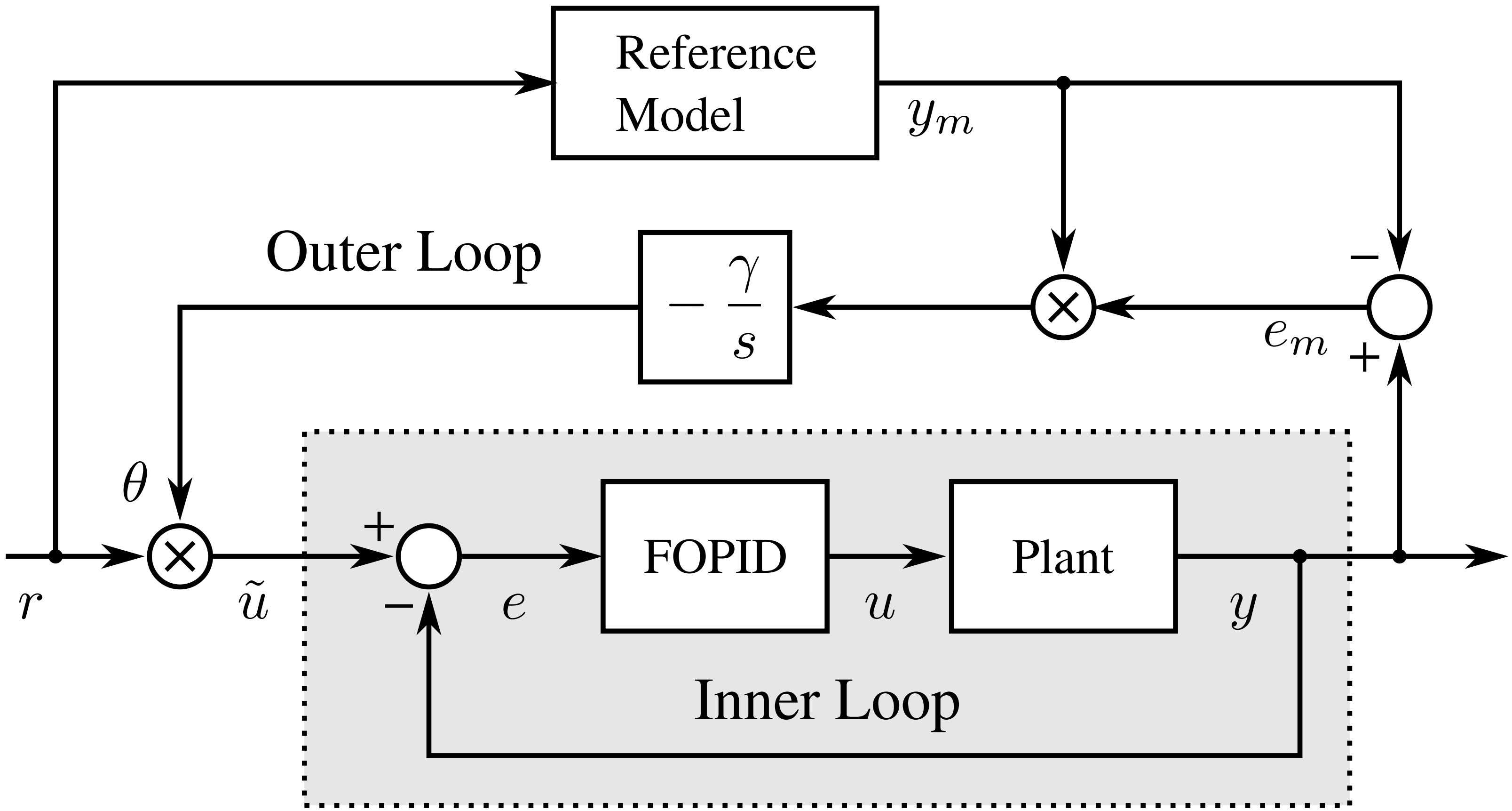


† A. Tepljakov, E. A. Gonzalez, E. Petlenkov, J. Belikov, C. A. Monje, and I. Petráš, "Incorporation of fractional-order dynamics into an existing PI/PID DC motor control loop ," ISA Transactions, vol. 60, pp. 262–273, 2016.

PRESENT APPROACH

- The proposed method requires a transfer function model of the closed loop control system, which is in fault-free, well-tuned and having satisfactory control performance.
- To obtain the transfer function, closed loop model identification can be carried out.
- This transfer function should be used as the reference model for the control system, and the outer loop performing feed-forward MIT rule should also be connected to input of the existing closed loop system to achieve input shaping.

SYSTEM STRUCTURE



MULTI-LOOP MRAC-FOPID SYSTEM

We assume that the FOPID controller is represented by

$$C_0(s) = k_p + k_i s^{-\lambda} + k_d s^{\mu} \tag{1}$$

and the plant by

$$G_0(s) = \frac{a_0}{b_2 s^{\alpha_2} + b_1 s^{\alpha_1} + b_0}. \tag{2}$$

This model is useful for a number of industrial processes.

MULTI-LOOP MRAC-FOPID SYSTEM

Then, the transfer function of the reference model $T_m(s)$ is

$$T_m(s) = \frac{C_0(s)G_0(s)}{1 + C_0(s)G_0(s)} = \frac{T_m^z(s)}{T_m^p(s)}, \tag{3}$$

where

$$T_m^z(s) = a_0 k_d s^{\mu+\lambda} + a_0 k_p s^{\lambda} + a_0 k_i, \tag{4}$$

and

$$\begin{aligned} T_m^p(s) = b_2 s^{\alpha_2+\lambda} + b_1 s^{\alpha_1+\lambda} \\ + a_0 k_d s^{\mu+\lambda} + (b_0 + a_0 k_p) s^{\lambda} + a_0 k_i. \end{aligned} \tag{5}$$

FEED-FORWARD MIT RULE FOR MRAC DESIGN

The feed-forward MIT rule is given by

$$\frac{\mathrm{d}\theta}{\mathrm{d}t} = -\gamma \frac{\mathrm{d}J}{\mathrm{d}\theta} = -\gamma e_m \frac{\mathrm{d}e_m}{\mathrm{d}\theta}. \tag{6}$$

For this system, the sensitivity derivative is

$$\frac{\mathrm{d}e_m}{\mathrm{d}\theta} = \frac{T(s)}{T_m(s)} y_m, \tag{7}$$

where $T(s)$ is the transfer function of the closed loop system, the adaptation gain can be expressed as

$$\theta = -\gamma \frac{1}{s} \left(\frac{T(s)}{T_m(s)} y_m e_m \right). \tag{8}$$

SYSTEM OPERATION: NORMAL CASE

In the case of normal operation when $T(s) = T_m(s)$ the update rule turns into

$$\theta = -\gamma \frac{1}{s} y_m e_m. \tag{9}$$

In the normal case, since the reference model and controlled plant match each other, we have $e_m = 0$. We have

$$e_m = T(s)\theta r - T_m(s)r = T_m(s)(\theta - 1)r = 0. \tag{10}$$

The occurrence of any fault can be diagnosed when $\theta \neq 1$.

SYSTEM OPERATION: FAULT CASE

In case of a fault or parametric perturbation $T(s) \neq T_m(s)$, and the adaptation gain θ is modified corresponding to a matching function

$$D(s) = T(s)/T_m(s). \tag{11}$$

The estimation and analysis of the function D(s) can allow the diagnosis of fault cases.

In this work, we consider a gain fault, where the transfer function is changed as $T(s) = kT_m(s)$, where $k \neq 1$.

SIMULATION STUDY

In a previous experiment[‡], closed loop identification of a system was performed using FOMCON toolbox, as a result the plant

$$G_0(s) = \frac{0.98}{0.886s^{2.55} + 1.328s^{1.254} + 1.0}. \tag{12}$$

was obtained. Then, a FOPID controller was designed

$$C_0(s) = 0.01 + \frac{0.53795}{s^{0.1}} + 0.84749s^{0.75} \tag{13}$$

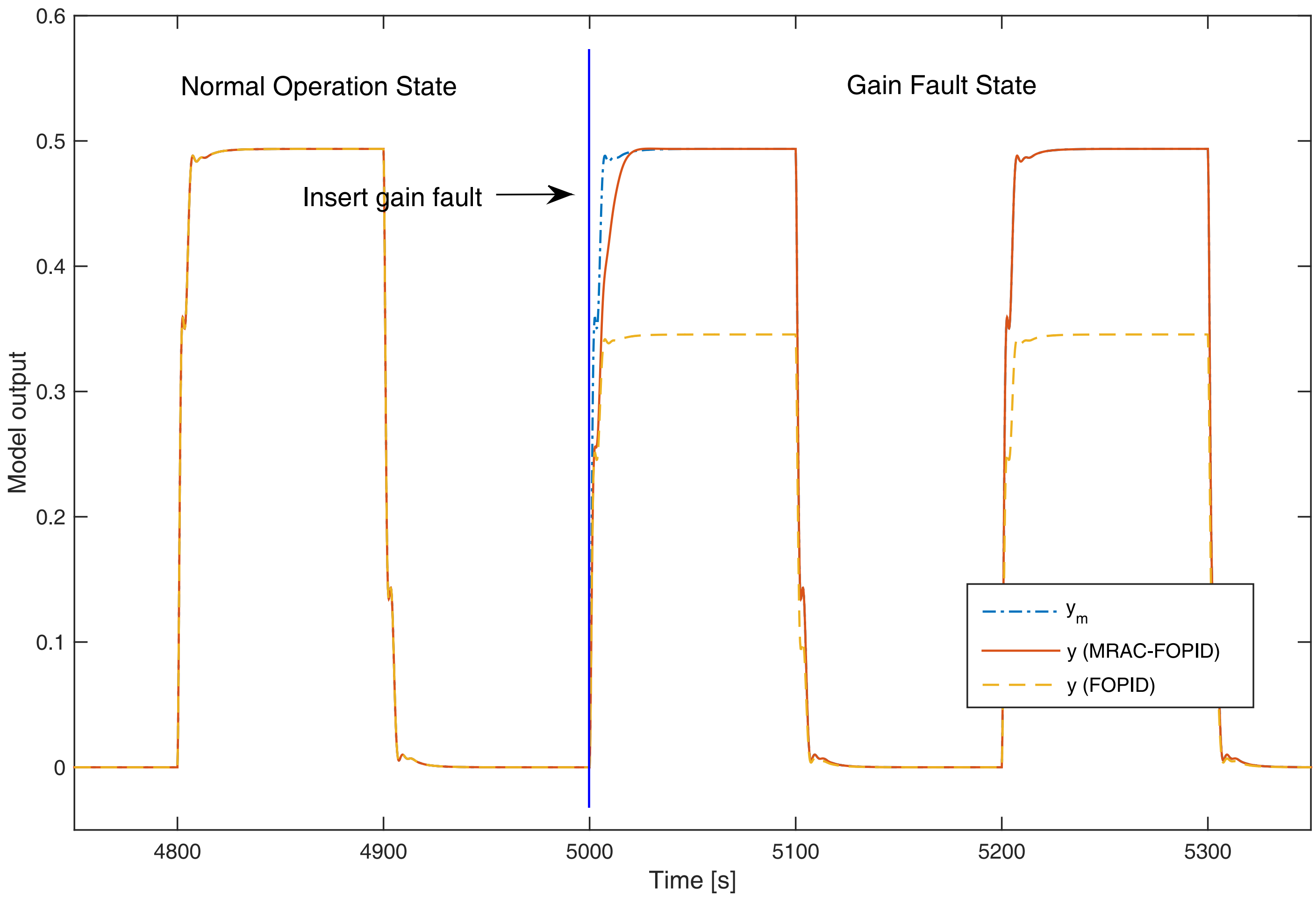
We reuse these results in this study and obtain the reference model $T_m(s)$ for the MRAC control system as discussed above.

[‡] A. Tepljakov, E. Petlenkov, and J. Belikov, “Closed-Loop Identification of Fractional-order Models using FOMCON Toolbox for MATLAB,” in Proc. 14th Biennial Baltic Electronics Conference, 2014, pp. 213–216.

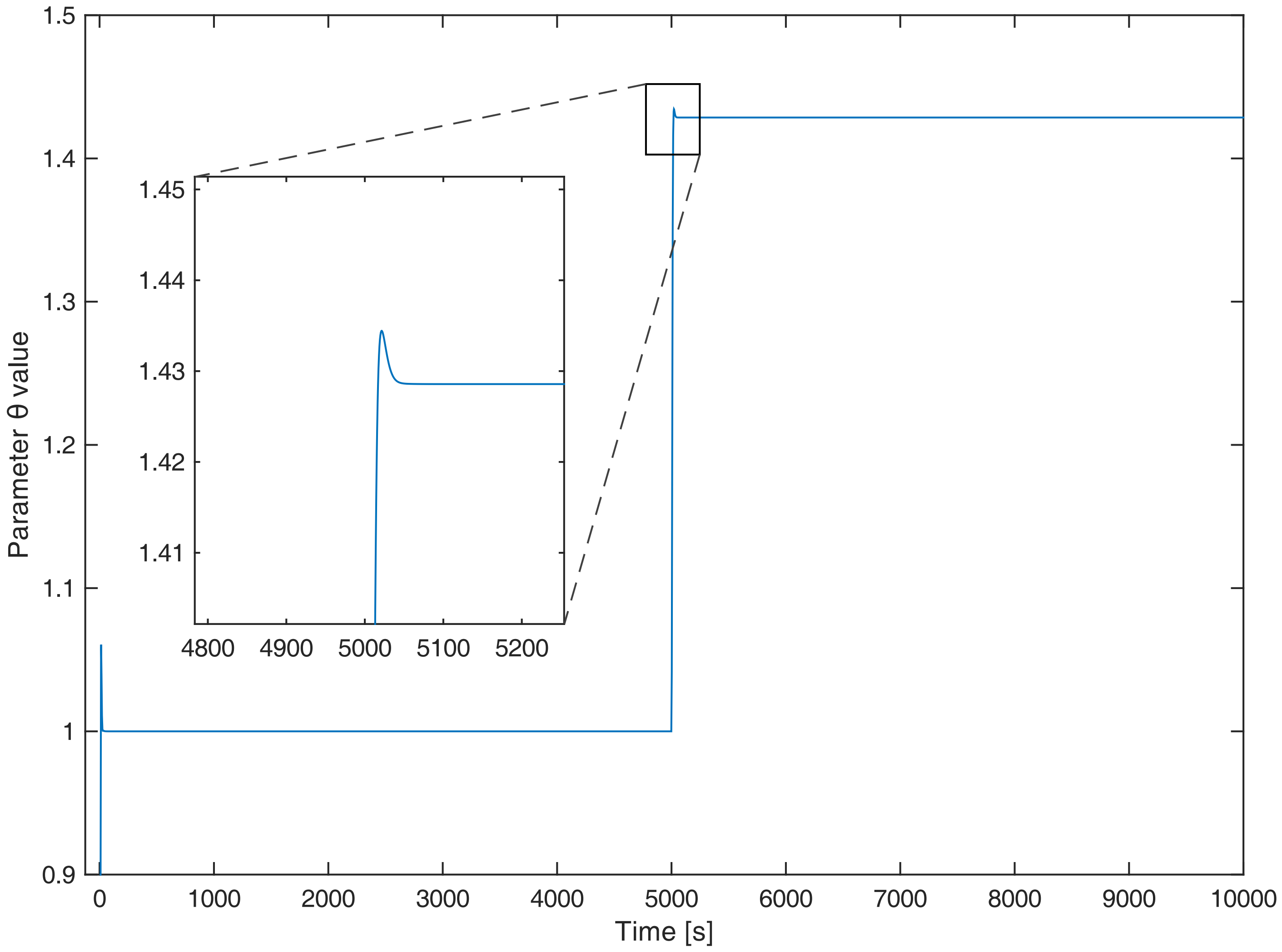
SIMULATION STUDY: SETUP

- The multi-loop MRAC-FOPID system was built and simulated in MATLAB/Simulink environment.
- To implement $T_m(s)$ in simulations, we used fourth-order CFE approximation.
- The parameter γ was set to one.
- The gain type fault case, modeled by $T(s) = 0.7T_m(s)$, occurred at the 5000th second of simulation.

SIMULATION RESULTS: MODEL OUTPUT



SIMULATION RESULTS: PARAMETER θ



CONCLUSIONS

- For mission-critical and remote control applications, fault tolerance and diagnosis are very important.
- The proposed method can allow detection of fault cases or anomalies of closed loop systems.
- The method is based on input-shaping strategy and so does not modify or tune any parameter of the closed loop control system.
- In this study, we demonstrated fractional-order control and modeling methods and the corresponding advantages of improved controller performance and system modeling in the context of MRAC control. Our findings are presently supported through software simulations.

ACKNOWLEDGEMENTS

CA15225 FRACTIONAL SYSTEMS

This article is based upon work from COST Action CA15225 (a network supported by COST, European Cooperation in Science and Technology).

ACKNOWLEDGEMENTS

IT Akadeemia
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This work was partially supported by IT Academy through a mobility scholarship.
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