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# Fault Accommodation in Technical Systems Based on Logic-Dynamic Approach

Vladimir Filaretov[a,b], Alexey Zhirabok[a,c*], Alexey Shumsky[a,c], Alexander Zuev[a,b]

[a]Far Eastern Federal University, Vladivostok, 690990 Russia
[b]Institute for Automation and Control Processes, 690041 Russia
[c]Institute of Applied Mathematics, Vladivostok 690041 Russia

**Abstract**

The paper is devoted to the problem of fault accommodation in nonlinear dynamic systems related to constructing the control law which provides full decoupling with respect to fault effects. Existing conditions are formulated and calculating relations are given for the control law. The logic-dynamic approach is used to solve the problem whose features are consideration of the systems with non-smooth nonlinearities and the use of relatively simple linear methods which may be supported by existing programming systems, e.g. MatLab.

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*Keywords:* Nonlinear systems; non-smooth nonlinearities; fault accommodation; full decoupling, logic-dynamic approach

## 1. Introduction

An increasing demand on reliability and safety for critical purpose control systems calls for the use of fault tolerant control (FTC) techniques. The goal of the FTC is to determine such a control law that preserves the main performances of the system in the faulty case while the minor performances may degrade. There are two principle approaches to the FTC [1, 4, 6, 7, 8, 11]. The first of them involves adaptive control techniques and assumes on-line fault detection and estimation followed by control law accommodation. The second approach is focused on such a control law determination which provides full decoupling with respect to fault effects in output space of the system.

* Corresponding author. Tel.: +79242345895
E-mail address: zhirabok@mail.ru


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In contrast to the first approach, the second approach does not need in fault estimation. Therefore, such approach looks reasonable if on-line fault estimation is problematic.

The problem of fault accommodation in dynamic systems was solved in [5, 9] based on differential geometry and algebra of functions and demands complex analytical calculations. In this paper, we use the logic-dynamic approach proposed in [2, 10]. The main idea of this approach is replacing the nonlinear system under consideration by certain linear one, solving the problem for this linear system involving linear methods and, finally, taking into account nonlinear terms to correct the obtained solution. The main features of the proposed approach are: (1) it considers the systems with non-smooth nonlinearities in dynamics, (2) it involves known linear methods that results in possibility to solve the fault accommodation problem by existing programming systems without using the symbolic software, (3) it can be applied both to discrete-time and continuous-time systems.

The logic-dynamic approach to solve the fault accommodation problem was considered in [3]. The present paper takes more sophisticate analysis that allows to obtain simpler solution (in particular, static solution) and extend a class of systems which the fault accommodation problem can be solved for.

To apply the logic-dynamic approach and to take into account the faults, it is assumed that the initial system $\Sigma$ is described by the following model

$$x(k+1) = Fx(k) + Gu(k) + C\begin{pmatrix} \varphi_1(A_1 x(k), u(k)) \\ \cdots \\ \varphi_p(A_p x(k), u(k)) \end{pmatrix} + Dd(k), \qquad y(k) = Hx(k)\,, \tag{1}$$

where $F$, $G$ and $H$ are the matrices of appropriate dimensions, describing a linear part of the system; $D$ is known constant matrix, $d$ is a vector, describing the faults: if a fault occurs, $d(k)$ becomes an unknown function of time, otherwise $d(k) = 0$ ; $C$ is $n \times p$ constant matrix; $\varphi_1, ..., \varphi_p$ are nonlinear functions which maybe non-smooth; $A_1, ..., A_p$ are row matrices.

It is assumed that the fault detection and isolation procedure is performed by known methods (see e.g. [1]). If a fault occurs, $d(k)$ becomes an unknown function, and a solution of the control problem based on the model (1) becomes impossible. To overcome this difficulty, one suggests to obtain the vector $u(t)$ according to the relation

$$u(k) = g(x_0(k), y(k), u_*(k)), \tag{2}$$

where $g$ is the vector function to be determined, $u_*(k)$ is a new control vector, $x_0 \in R^{n_0}$, $n_0 \le n$, is a state vector of the system $\Sigma_0$ described by the model

$$x_0(k+1) = F_0 x_0(k) + G_0 u_*(k) + J_0 y(k) + C_0 \varphi(A_0 \begin{pmatrix} x_0(k) \\ y(k) \end{pmatrix}, u_*(k)), \tag{3}$$

where $F_0, G_0, J_0, C_0, A_0$ are the matrices to be determined.

Assume that the control (2) exists and the fault occurred and was detected, then a solution of the control problem is performed on the basis of the additional system $\Sigma_*$ described by the model

$$x_*(k+1) = F_* x_*(k) + G_* u_*(k) + C_* \varphi(A_* x_*(k), u_*(k)), \tag{4}$$

corresponding in a definite sense to the initial model (1); here $F_*, G_*, C_*, A_*$ are the matrices to be determined. Note that (4) does not contain the unknown vector $d(k)$. Therefore, fault accommodation effect may be achieved by using the model (4) for control determination.

The problem under consideration is to determine the existing condition for the control (2) and to obtain the function $g$ and the matrices, describing the systems $\Sigma_0$ and $\Sigma_*$.