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How to Formulate the Problem of Dependable Control with Actuator Faults

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The paper by Ge Guo [3] formulates and solves the robust stochastic control problem for a certain class of cooperating linear actuators. Although the paper does not mention faults, the activation states of the actuators can be interpreted as faults. The system under consideration (Fig. 1) contains a Markov model for the faults, a fault independent process model with (bounded variable) time delay and modelling errors, and a very simple fault dependent actuator model (individual actuators are assumed to be either active or not). The goal is for the state error integral

$$\int_{t=0}^{\infty} E \left\langle |\mathbf{x}(t)|_2^2 \right\rangle dt$$

to exist and to be bounded for each initial fault state.

This approach is clearly structured, implementable, and powerful. It leads to a linear stochastic model for the overall system, and it addresses valid problems faced in real engineering systems. However, it also excludes a number of aspects that are often considered essential for dependable systems, such as a worst case analysis, system limits, observation errors, and possibly non-linear effects and changes to the system model itself.

These choices are inherent in the formulation of the fault tolerant control problem. So in order to fully appreciate this paper, it is worth highlighting

Figure 1: The Diagram of the Problem Formulation

the choices made, how they relate, and how they determine the solution. The literature of dependable systems and fault tolerant control looks at many distinct problem formulations, and although no consensus is expected to arise, spelling out the differences can help to understand the relationship between the results.

The first decision is whether to include the problems of information availability: health monitoring, fault detection and identification (FDI), state estimation etc. Guo assumes that both the state x and the fault M_ρ^j are known at every point in time, leading to what is called a full information problem. The FDI problem can usually be solved separately, and then included in the control problem as a stochastic Markov model [2], enabling a stochastic analysis of the whole system. It seems that this approach is applicable here by assuming a distinction between the actual and the detected fault state (both M_ρ^j in the paper).

The next decision is whether to analyse the average case or the worst case; it is the difference between looking for $E \left\langle |\mathbf{x}|_2^2 \right\rangle$, the average according to

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a stochastic fault model, or $\max |\mathbf{x}|_2$, the worst case over a number of considered faults. This decision is crucial, because it leads down very different theoretical approaches, and it also implies very different meanings for the result.

From an economic perspective, the expected average case is the relevant one, and the remaining risk can be accepted or insured. But the certification of dependable systems often requires looking at the worst case. Of course the true worst case of any system is the complete failure of all components, therefore additional assumptions are typically introduced to limit the combinations of faults to be considered (e.g. only single and double faults), which leads to classical solutions such as triple vote or four way redundancy [3].

The choice between the two approaches depends mainly on the dynamics of the fault model. If the fault state and the process state change on similar time scales, a stochastic approach is indicated, leading to a joint (stochastic) model. But if faults last for a long time compared to the system dynamics, the worst case approach may be more useful.

Finally the system model also plays a significant role—especially how it changes under fault conditions. The model matching approach offers an opportunity to extend the range of faults to include any change in system dynamics [4]. On the other hand faults in the system dynamics ($\mathbf{A}$ matrix) can be mapped on faults in the input matrix ($\mathbf{B}$), but this causes additional complexity in the process model and consequently the solution [5].

In conclusion, the presented paper pushes the reconfiguration problem into a new and distinct direction. It can be pursued further, e.g. by including the influence of FDI, and it could make a significant contribution to the closely related field of fault tolerant control.

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