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Fault-tolerant control after sensor and actuator failures

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1 Fault-tolerant control

Fault-tolerant control (FTC) aims at increasing the availability of processes subject to faults or failures. The active fault-tolerant control scheme, as described in [1], is shown in Fig. 1.

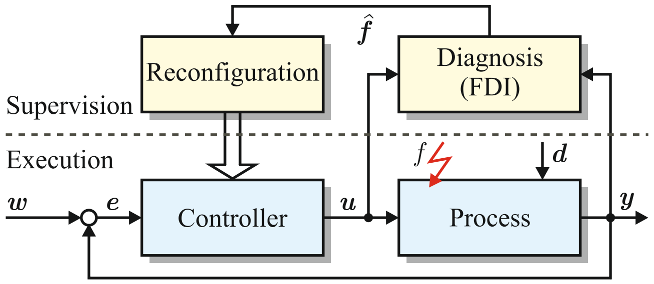


Figure 1: Active fault-tolerant control scheme

The **f**ault **d**iagnosis and **i**dentification (FDI) block has to detect, localize and identify the fault by measuring the input and output signals of the plant. Based on the diagnosis result the reconfiguration block has to adapt the controller in such a way that the new controller is able to cope with the faulty process.

2 Project aim

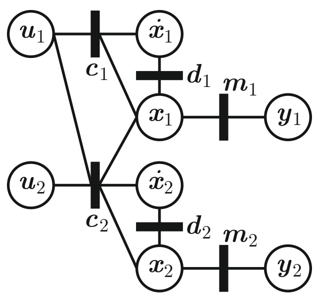
The aim of the project is to elaborate a complete fault-tolerant control framework as shown in Fig. 1 for systems subject to failures of sensors and actuators. These so-called major faults cause an important reconfiguration problem. The feedback is partially broken-off and parts of the plant are controlled in an open-loop structure. A solution for the reconfiguration step after sensor and actuator failures is given by the concepts of the virtual sensor and the virtual actuator [1, 4, 5].
These methods assume an ambiguous, previous detection and localization of the failure. Therefore a method for active, consistency-based failure detection and isolation has to be elaborated. In general the result of the diagnosis step is a set of possible failure candidates or affected by other uncertainties. The accuracy of the diagnosis result is expected to increase by the aggregation of the diagnosis and the reconfiguration step.
Until now the reconfigurability analysis and the design of the reconfiguration block works on a holistic model-based description of the system. Thus, the reconfigured controller makes use of every available component. Depending on the system's structure the failure usually affects only a part of the system. An overall reconfiguration block especially is harmful in decentralized control systems. Currently reconfiguration leads to centralization even if the faulty subsystem is reconfigurable itself. Therefore a reconfiguration analysis should provide methods

- to identify the system part affected by the failure.
- to identify useful components for reconfiguration.
- for decentralized reconfiguration.

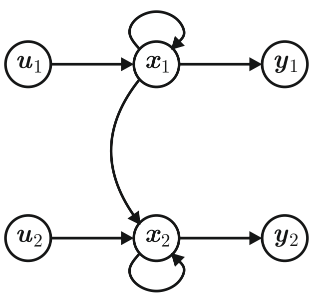
The aim is to reduce the reconfiguration block to the system part assumed to be affected by the failure. This in fact is expected to improve the diagnosis, too. The verification or exclusion of the diagnosis result used for reconfiguration possibly can be abbreviated. Therefore, if necessary, a new diagnosis step with more information can be performed earlier.

3 Structural analysis

The part of the system affected by a certain failure as well as the components that account for reconfiguration mainly depend on the system structure. Therefore a preliminary reconfiguration analysis based on a structural description of the system is performed.
In literature there exist several types of structural system models. Two commonly used descriptions are the bipartite graph [1] and the di-graph [2, 3, 5]. The former is shown Fig. 2(a) and the latter in Fig. 2(b). It has to be figured out which one is suitable for the reconfiguration analysis. The failure propagation for example can directly be seen in both of the structural models by creating the reachability graph of the failed component.



(a) Bi-partite graph



(b) Di-graph

Figure 2: Structural models of dynamical systems

May 12, 2013

The numerical reconfigurability conditions stated in [5] essentially are based on the stabilizability and detectability of the faulty system. The recovery of further performance requires some additional rank conditions to be fulfilled, representing the available redundancies in the system. It has to be investigated how the reconfigurability conditions deposit in the different structural models. Then it is possible to pre-decide which failure is reconfigurable and which components account for reconfiguration in a structural sense.
The expected result a reduced structural model containing only the components of the system that are necessary to reach a desired reconfiguration goal. These structural models are the basis for the design of the reduced numerical reconfiguration blocks and the solution of the problems described in Sec. 4 and Sec. 5.

4 Reduced reconfiguration blocks

In literature, the reconfiguration block concerns all existing sensors and actuators, no matter if it is used by the nominal controller or not. This brings up the problem, that after reconfiguration every component is in use. This is because the design process does not consider if a sensor or actuator really accounts for reconfiguration. It is also possible that there exist multiple sensors and actuators with similar impact on the process where it is sufficient to choose one.

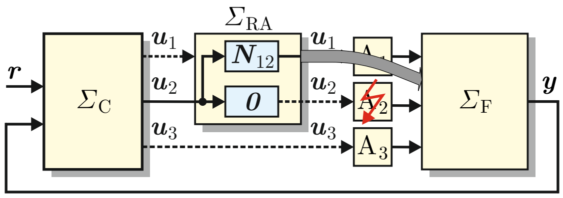


Figure 3: Reduced reconfiguration block

The aim is to design a reconfiguration block that only uses the required components. An example for the expected is shown in Fig. 3 for static virtual actuator.
The design of the numerical reconfiguration block requires to check whether the identified components for reconfiguration also provide a solution in the numerical sense. If not, this solution has to be excluded and another structural model has to be found. For the case of multiple, comparable solutions in the structural sense a quantitative criterion for selection has to be elaborated.

5 Decentralized reconfiguration

By now, the design of the reconfiguration block for physically interconnected subsystems concerns an overall system model. In a decentralized nominal control scheme this always leads to a centralized reconfigured control loop.
This part of the project aims at designing a decentralized reconfiguration block as shown in Fig. 4. It has to be analyzed if the decentralized control loop containing

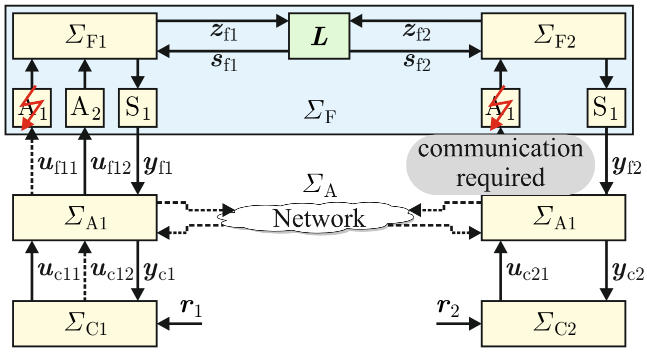


Figure 4: Decentralized reconfiguration

the failed componentis reconfigurable itself. If not it has to be checked if there exists components in other subsystems that allow cooperative reconfiguration. The ladder directly answers the question which information links are useful.
Again the analysis is first done in a structural sense. The verification of the numerical solution has to be done with respect to the overall system stability. Moreover it has to be analyzed if a decentralized design of the reconfiguration block is feasible.
It is assumed that the given decentralized controller is able to control a subsystem with a certain performance without knowledge about the other subsystems. It is therefore desirable to reconfigure the I/O-behavior with respect to the coupling signals $\boldsymbol{s}_{\mathrm{f}i}(t)$ and $\boldsymbol{z}_{\mathrm{f}i}(t)$. In this case, the performance of the remaining decentralized control loops would be unchanged.

6 Application: multicopter

The results of this project will be evaluated on the example of multicopters. These are flying vehicles with multiple rotors in a symmetric arrangement. It is expected that up from a number of 5 rotors there exists sufficient redundancy to compensate the complete loss of an actuator. Therefore the concurrent project is the modeling of several multicopter and the setup of an experimental environment for verification of the theoretical results.

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