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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.

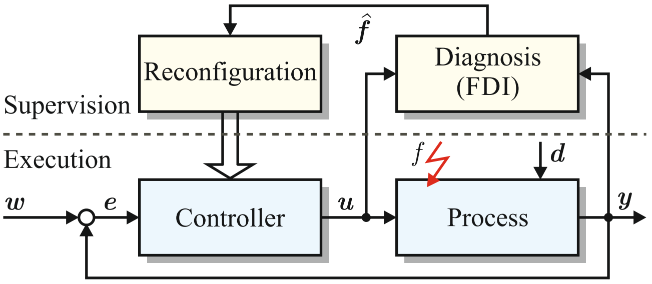

Figure 1: Active fault-tolerant control scheme

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. Such major faults cause an important reconfiguration problem. The feedback is partially broken 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, 2, 4].

These methods assume a previous detection and localization of the failure which is unique. The current project aim is to refuse this assumption and to elaborate a consistency-based detection and isolation method for sensor and actuator failures. The accuracy of the diagnosis should be as high as possible. Therefore the diagnosis unit should be

- active (use test signals for best possible isolation).
- robust against unknown inputs (disturbances).
- able to order remaining fault candidates by their probability.

In general in will not be possible to get a unique diagnosis result with no uncertainties. The accuracy of the diagnosis result is then expected to increase by the aggregation of the diagnosis and the reconfiguration step. In fact it has to be proven if failures that are not distinguishable from regarding the I/O behavior have a common solution of the reconfiguration problem. If not, the reconfiguration step might verify or dismiss the current fault candidate and, if necessary, a new diagnosis step with new information can be performed.

3 Active failure detection and isolation

For the reconfiguration step with a virtual sensor or a virtual actuator a certain and unique diagnosis result is needed. The scheme of a consistency-based diagnosis as introduced in [1, 3] unit is shown in Fig. 3.

The diagnosis unit again consists of two blocks. First the residual generator. This block uses a model of the plant, here an observer, that is placed parallel to the process. A residual $\boldsymbol{q}$ is generated by comparing the process output and the model output. If they distinguish, the residual differs from zero. The second block, the residual evaluation weights the residual and compares it to a threshold to decide if the model is still consistent with the plant behavior and therefore whether the residual indicates fault or not.

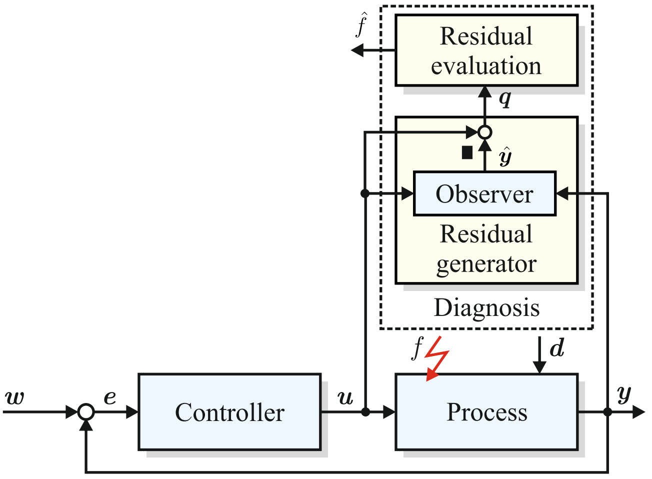

Figure 2: Observer-based diagnosis

To not only decide if a fault occurred but also which one more than one residual is needed. The idea therefore is to use a bank of observers, also presented in [3]. This bank contains not only the model of the nominal plant but also the faulty model of every regarded fault. More residuals are generated by comparing the plant output and the model outputs of the faulty models. The residual that does not differ from zero (only within the threshold) indicates the fault model that is consistent with the current plant behavior and therefore which fault occurred.

In general the problems in the diagnosis step derive from model uncertainties, measurement noise, unknown inputs (disturbances) and fault candidates that cannot be isolated. In the case of model-based (observer-based) it is assumed that the process model is sufficiently accurate. The observer is also robust against measurement noise. The main difficulties in observer-based diagnosis therefore result from unknown inputs and fault that cannot be isolated.

To be more robust against disturbances, unknown input observers should be used to decouple the influence of unknown inputs from the state estimation.

In this project an active consistency-based diagnosis unit should be elaborated. An active diagnosis unit cannot only measure the plant's inputs and output. It also can generate test signals to excite the plant in a specific manner. It is expected that, because of considering sensor and actuator failures, some test signals will improve the isolation step. It also should help to decide if a residual deflection is caused by a fault or an unknown input. As described in Sec. 4 the active diagnosis can also improve the fault isolation step on a structural level.

If it is not possible to completely isolate the fault candidates, the remaining ones should be ordered and evaluated by their probability. The next part of the project will show if those fault candidates have to be distinguished or have a common solution of the reconfiguration problem. If not, a reconfiguration based on the probability order can give further information if the reconfiguration problem is solved or not. It can be sufficient to show that the plant does not get unstable and a new reconfiguration with the next fault candidate can be performed.

4 Structural analysis

The part of the system affected by a certain failure as well as the capability to detect or isolate certain faults from each other or unknown inputs mainly depend on the system structure. Therefore a preliminary analysis based on a structural description of the system is performed.

In [1] a bipartite graph description of the system as shown Fig. 3 is used to analyze whether a certain fault is detectable or not and which faults and disturbance inputs are distinguishable. It has to be figured out under which conditions it is possible to structurally decouple the diagnosis unit from the influence of unknown inputs and to design a structured residual generator considering the different sensor and actuator failures.

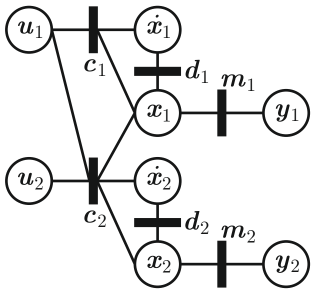

Figure 3: Bipartite graph

In literature there also exist approaches that show how active fault detection and isolation methods can improve the diagnosis result already on a structural level. It is expected that in cases of sensor or actuator failures the use of active diagnosis leads to a significant improvement of the detectability and isolation properties. In some cases it is also possible to steer a system in a certain point, where some signal connections vanish and an exclusion of further fault candidates is possible.

Furthermore it has to be proven if the failures that affect the same part of the system cannot be isolated by exciting and observing certain inputs and outputs need the same parts and components of the system for reconfiguration.

5 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. For a quad-rotor the loss of an actuator is not reconfigurable without the loss of the yaw control. Up from a number of 6 rotors there exists sufficient redundancy to compensate the complete loss of an actuator. In the case of 8 rotors for every rotor there is a redundant component. After modeling the different multicopter and the design of a position controller, the concurrent aim of the project is to solve the diagnosis and reconfiguration problem for a multicopter with 6 and 8 rotors. The theoretical results should than be verified in the experimental environment.

References

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