Geometric and Data-driven Solutions of Detection Problems in Dynamic Systems and Networks

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Detection of unknown inputs affecting dynamical systems appears in various applications. One problem formulation is called fault detection (FD) and isolation (FDI) where the changes interpreted as faults in some cases, enter the system as an additional disturbance (fault) signal. The goal is then either to decouple the effect of these signals from certain sensor measurements (outputs) of the system or to detect (reconstruct) their occurrence based on the available information.

Fault detection and isolation is also relevant for constructing safety-related control systems. Here the estimated fault signal can be used in control reconfiguration. Unlike robust control, reconfigurable control systems allow to reuse the fault related information in order to modify the control law.
Related algebraic approaches include unknown input observer (UIO) design and parity space methods. Statistical approaches rely on generalized likelihood, multiple model and parameter estimation strategies.

A prototype problem for FDI was formulated originally in the linear time invariant (LTI) framework as the fundamental problem of residual generation (FPRG).
This was solved using geometric approaches based on state-space modelling and a construction of suitable invariant subspaces. The design ended in fault detection filters that were thoroughly analyzed for sensitivity, robustness and performance properties.

This solution was defined first in terms of an LTI state-space framework and the detection filter was designed using geometric methods. Many problems need nonlinear modelling originally, thus finding solutions for the nonlinear case was an important problem, too. While the geometric theory for nonlinear FPRG had existed, the implementation was not straightforward at all. Since construction of invariant subspaces for affine linear parameter varying (qLPV) systems was already available, the embedding of nonlinear state-space models into qLPV models was a promising solution. This effort inspired the development of several solutions to the qLPV FPRG problem.

After some general considerations we provide a short introduction to the LPV modelling and give the elements of an i/o interpretation of an LPV systems. Based on this interpretation the fundamental problems concerning LPV fault detection are formulated. The model based and data-driven computation of the relevant invariant subspaces will be characterized, too.

Some examples will be shown for illustration, application in aircraft failure detection and attack detection in networks and formation flying will also be discussed.