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Fault Diagnosis and Fault-Tolerant Control of Bilinear-Systems: Application to Heating, Ventilation, and Air Conditioning Systems in Multi-Zone Buildings

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Abstract : Over the past decade, the growing demand for energy efficiency in buildings has attracted the attention of the control community. Failures in HVAC (heating, ventilation and air conditioning) systems in buildings can have a significant impact on the desired and expected energy performance of buildings and on the user's comfort as well. FTC is a recent technology area that studies the adaptation of control algorithms to faulty operating conditions of a system. The application of Fault-Tolerant Control (FTC) in HVAC systems has gained attention in the last two decades. The objective is to maintain the variations in system performance due to faults within an acceptable range with respect to the desired nominal behavior. This paper considers the so-called active approach, which is based on fault and identification scheme combined with a control reconfiguration algorithm that consists in determining a new set of control parameters so that the reconfigured performance is "as close as possible, "in some sense, to the nominal performance. Thermal models of buildings and their HVAC systems are described by non-linear (usually bi-linear) equations. Most of the works carried out so far in FDI (fault diagnosis and isolation) or FTC consider a linearized model of the studied system. However, this model is only valid in a reduced range of variation. This study presents a new fault diagnosis (FD) algorithm based on a bilinear observer for the detection and accurate estimation of the magnitude of the HVAC system failure. The main contribution of the proposed FD algorithm is that instead of using specific linearized models, the algorithm inherits the structure of the actual bilinear model of the building thermal dynamics. As an immediate consequence, the algorithm is applicable to a wide range of unpredictable operating conditions, i.e., weather dynamics, outdoor air temperature, zone occupancy profile. A bilinear fault detection observer is proposed for a bilinear system with unknown inputs. The residual vector in the observer design is decoupled from the unknown inputs and, under certain conditions, is made sensitive to all faults. Sufficient conditions are given for the existence of the observer and results are given for the explicit computation of observer design matrices. Dedicated observer schemes (DOS) are considered for sensor FDI while unknown input bilinear observers are considered for actuator or system components FDI. The proposed strategy for FTC works as follows: At a first level, FDI algorithms are implemented, making it also possible to estimate the magnitude of the fault. Once the fault is detected, the fault estimation is then used to feed the second level and reconfigure the control low so that that expected performances are recovered. This paper is organized as follows. A general structure for fault-tolerant control of buildings is first presented and the building model under consideration is introduced. Then, the observer-based design for Fault Diagnosis of bilinear systems is studied. The FTC approach is developed in Section IV. Finally, a simulation example is given in Section V to illustrate the proposed method.

Keywords : bilinear systems, fault diagnosis, fault-tolerant control, multi-zones building
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