DIPARTIMENTO DI INGEGNERIA
CORSO DI DOTTORATO IN INGEGNERIA INDUSTRIALE E DELL'INFORMAZIONE -
PHD COURSE IN INDUSTRIAL AND INFORMATION ENGINEERING - 36TH CYCLE

Title of the research activity:	**Machine learning and Statistical Techniques for the Robust Fault Diagnosis and Prognostics of Mecatronic, Robotic and Industrial systems.**
State of the Art:	Failure diagnosis in industrial, robotics, automotive and biomedical systems plays a relevant role in many engineering fields, especially in applications where the occurrence of a failure may have a significant impact on the safety of human beings. These safety and reliability aspects are very important for instance in biomedical and aerospace systems. In many applications it is therefore essential to detect and suddenly isolate the faulty components of a system and to take the appropriate corrective actions before the fault propagation produces unrecoverable consequences. It is important not only the real time diagnosis of failures but also to predict, in advance, the possible future occurrence of failures (Prognostics). There are many approaches in the literature for the design of fault diagnosis systems [1-6]. In most cases, the diagnostic systems are based on a mathematical model that reproduces, in real time, the response of the real system in nominal conditions. This model makes it possible to detect the occurrence of a potential failure by monitoring the difference (named "residual") between the actual response of the system and the response the model. In case the residual exceeded a defined alarm threshold a fault is declared. In more details before the decision blocks ("detector"), the residual signals are filtered and processed in order to minimize the occurrence of false alarms and to maximize the sensitivity to faults. In this regard, there is a rich literature dealing with residual filtering techniques in the presence of uncertainties, noise and autocorrelation in the diagnostic signals [1-6]. There are essentially two approaches to fault diagnostics known as "active approaches" and "passive approaches". Active methods, developed mainly before the 2000s, design residual generators that, by construction, are robust to model uncertainties and measurement noise and are sensitive to a limited set of specific faults. In this case, most of the design effort is focused on the development of robust and decoupling filters, while the fault detection logic is often a simple threshold detector operating on the mean value of the diagnostic signals [1-6]. Passive approaches [7-14] have been developed mainly after 2000. These methodologies quantify the modeling uncertainties at design stage and propagate their effects to the decision block. Typically, these approaches are based on parametric interval models or "set-membership approaches". In these approaches the estimation is not a single value rather a range of values that contains the true value with a desired confidence. These methods produce a range of admissible values for residual signals whose extreme can be interpreted as time varying thresholds useful for fault detection and isolation. Recently also data driven statistical process control technique have been widely applied in practice [15]. The performance of a generic fault diagnosis system depends on the accuracy and reliability of the mathematical models. The more a model reproduce accurately the response of the real system, the more it will be possible to detect the occurrence of small amplitude faults. Most of the fault diagnosis techniques for complex systems proposed in the literature have been evaluated on simulation and benchmark models. Such studies, although important from a theoretical point of view, often provide unsatisfactory performance when applied to real data. The reasons for this loss of performance depends on multiple factors such as system unmodelled dynamics, uncertainty in the dynamics of actuators and sensors, physical and computational delays, measurement and process noise, correlation in the diagnostic signals, etc. The proposed research activity originates from the these practical problems and proposes the study of robust fault diagnosis techniques and their validation using experimental data

	taken from real mecatronic and industrial systems.
Short description and objectives of the research activity:	The proposed research project can be summarized as follows: • Development of data-driven scheme for the design of interval models for the derivation of robust Analytical Redundancy Relations (AARs). These techniques are robust in the sense that propagate the modeling uncertainty to the output estimation. • Development of interval models-based Robust Observers and Robust Extended Kalman Filters. • Development of data-driven models for the identification of linear and non-linear interval models: AR, ARX, FIR, OE and NARX models, Adaptive Neural Network Models. • Application of Machine learning techniques. • Application of Statistical process control techniques [15]. • Development of fault detection and isolation schemes specifically designed for the developed models. • Test of the proposed algorithms on real flight data of civil airplanes, UAVs and terrestrial Robots. • Use of the recent probabilistic techniques [16] applied to interval models in order to rigorously quantify the probability of false alarms and failure isolation. The research activity (publications) of the member of the Automation research group in the field of Fault Diagnostics can be found in: https://scholar.google.it/citations?user=0GsU6UAAAAAJ&hl=en&oi=ao Co-tutoring The proposed project is interdisciplinary and it is relevant from an industrial and information engineering point of view. Therefore it could be developed in co-tutoring with other researcher of the Department of Engineering that are interested in fault diagnosis.
Bibliography:	[1] J. Chen and R. J. Patton, (2000) Robust Model-based Fault Diagnosis for Dynamic Systems. Kluwer Academic Publishers, (1st ed.), 1999. [2] Patton R.J., Frank P.M., and Clark R.N. (2000) Issues of Fault Diagnosis, for Dynamic Systems. Berlin, Germany: Springer-Verlag. [3] Gertler J. (1998). Fault Detection and Diagnosis in Engineering Systems. New York: Marcel Dekker. [4] Isermann R. (1984). Process fault detection based on modeling and estima-tion methods: a survey. Automatica, vol. 20, pp. 387–404. [5] Baseville M. (1988). Detecting changes in signals and systems: a survey. Automatica, vol. 24, no. 3, pp. 309–326. [6] Simani S., Fantuzzi C. and Patton R.J. (2002). Model-Based Fault Diagno-sis, in Dynamic Systems Using Identification Techniques, 1st ed. London, U.K.: Springer-Verlag. [7] Milanese, M., Norton, J., Piet-Lahanier, H., & Walter, É. (Eds.). (2013). Bounding approaches to system identification. Springer Science & Business Media. [8] Horak DT. Failure detection in dynamic systems with modelling errors. Journal of Guidance, Control, and Dynamics 1988; 11(6):508–516. [9] Emami-Naeini A, Akhter MM, Rock SM. Effect of model uncertainty of failure detection: the threshold selector. Trans. on Automatic Control 1988; 33(12):1106–1115. [10] Fagarasan I, Ploix S, Gentil S. Causal fault detection and isolation based on a set-membership approach. Automatica 2004; 2099–2110. [11] Puig V, Quevedo J, Escobet T, Nejjari F, de las Heras S. Passive robust fault detection of dynamic processes using interval models. IEEE Transactions on Control Systems Technology 2008; 16:1083–1089. [12] Sainz MA , Armengol J, Vehí J. Fault detection and isolation of the three-tank system using the modal interval analysis. Journal of Process Control 2002; 12(2):325–338. [13] Ploix S, Adrot O. Parity relations for linear uncertain dynamic systems. Automatica 2006; 42(9):1553–1562. [14] Alamo T, Bravo JM, Camacho EF. Guaranteed state estimation by zonotopes. Automatica 2005; 41(6):1035–1043. [15] Ding, Steven X. Data-driven design of fault diagnosis and fault-tolerant control systems. London, UK:: Springer, 2014. [16] Campi, M.C., Calafiore, G. and Garatti, S., 2009. Interval predictor models: Identification and reliability. Automatica, 45(2), pp.382-392.
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