Nonlinear Filtering for Prognostics and Health Management

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ABSTRACT

This document describes a Ph.D. thesis currently being developed on the theme of Prognostics and Health Management. This is part of an application for attending the PHM Society Doctoral Consortium. The outline of the thesis is described, which is related to the investigation of the application of nonlinear filtering techniques for PHM. The document also presents the expected contributions and proposed plan.

1. OUTLINE OF THE THESIS

Various different approaches are proposed in the literature for accomplishing failure diagnostics and prognostics on the context PHM. In the recent years, non-linear filtering and more particularly particle filtering (PF) has gained a lot of attention and has even been claimed to be the "de facto state of the art in failure prognosis" (Orchard et al., 2008). Various recent works have demonstrated successful applications of PF for failure diagnostics and prognostics of systems/components such as turbine blades and helicopter planetary gear plates (Orchard, 2007), batteries (Saha and Goebel, 2008), aircraft actuators (Brown et al., 2009), industrial processes (Morales-Menéndez et al., 2002) and others. There are many variations of the PF described in the literature. The choice of the importance function and resampling technique are among the subjects that may vary from one implementation to another. Some schemes such as the Rao-Blackwelised Particle Filter RBPF are specially suited for PHM applications (de Freitas, 2002), however, the application of PF for PHM is still an open research field and it is a very active research topic in the PHM community.

Despite being a very powerful tool, particle filtering also presents some drawbacks. The major drawback is probably the computationally intensive calculations required to perform the Monte Carlo simulations that are the core of the algorithm. This provides motivation for investigating also different nonlinear filtering techniques which may be more adequate for certain applications. In particular, the Unscented Kalman Filter (UKF) which is a very powerful nonlinear filtering method that has proven to be useful in other domains such as nonlinear state and parameter estimation (Wan and van der Merwe, 2000), has been given little attention in which concerns to PHM. Some examples in the literature of the successful application of the UKF for PHM include monitoring and failure diagnostics of turbine engines (Dewallef and Léonard, 2003). Among the relatively few applications of the UKF for failure diagnostics and prognostics described in the literature there are also combinations of the method with particle filters. Namely, the Unscented Particle Filter and (UPF) (van der Merwe et al., 2001) and the Gaussian Particle Filter (GPF) (Hutter and Dearden, 2003) which uses the UKF in combination with PF to provide an algorithm that is closely related to the RBPF and demonstrated to provide good results for failure diagnostics of hybrid systems.

The objective of the thesis described here is to investigate and propose novel applications of nonlinear filtering methods for PHM. Initial focus is being given to methods based on UKF and PF, comparing its capabilities and performance to the current state of the art.

Based on the assumption that different classes of systems may be better monitored using different PHM solutions, the scope of the applications to be investigated have also been restricted. Focus is being given to applications that are relevant to the aerospace domain, mainly applications related to commercial and military aviation.

2. EXPECTED CONTRIBUTIONS

The thesis described in this document is expected to provide the following main contributions:

1. Novel methodologies for using nonlinear filtering techniques for PHM;
2. Evaluation on limitations and recommendations on the application of such techniques;
3. Validation of the proposed methodologies through case studies related to the aerospace domain, using simulated and real data.

3. PROPOSED PLAN

The development of the thesis described in this document has started on August, 2008 and the expected graduation date is July, 2012. Therefore, the developments are still in the early stages. The following sections describe the work performed and what is planned as future work.

3.1 Work Performed

After an initial bibliography review (which keeps as a continuous effort), hands on work has begun on a simple simulated application. For this initial effort the goal was to choose a system that was simple enough to provide easy means for testing the concepts under study and complex enough in order to allow the initial evaluation of the capabilities of the methods. Besides, the system should pertain to the chosen application domain of commercial and military aviation. For this purpose, the chosen system was comprised of a brushless dc (BLDC) motor that is speed-controlled in closed loop to drive a propeller in order to provide controlled lift for a certain airborne vehicle. Such a system may be applied, for instance, for propelling mini-unmanned airborne vehicles (mini-UAVs) such as helicopter-like UAVs or quadrotors. Despite being simple, this system comprises some interesting nonlinearities such as Coulomb friction and aerodynamic loads. Besides, the aerodynamic load disturbances caused by gusts (process noise) are dependent on the propeller speed, which provides a time-varying behavior for such disturbance. Sensor noise has also been added for both motor speed and current sensors, which are the available measurements. Figure 1 presents a sample diagnostics of flux weakening of the permanent magnet of the motor starting at sample 800. It can be noticed from the figure that the fail flag correctly indicates the failure from this time instant. This has been accomplished using sampling importance resampling (SIR) PF with 100 particles.

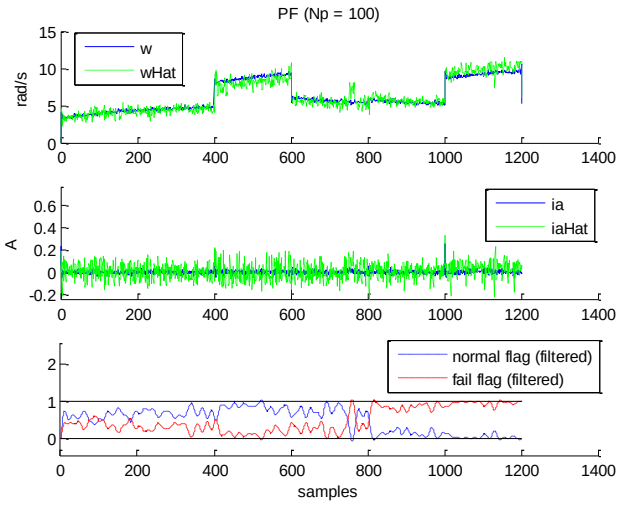

Figure 1. Flux weakening diagnostics using SIR PF.

Currently, effort is being made to perform fault detection of relevant failure modes using nonlinear filtering methods commonly used on the literature, mainly those based on PF, and also test UKF based approaches and compare the results. This effort is planned to be developed in order to be possible to present preliminary results during the PHM Society Doctoral Consortium.

3.2 Future Work

It is expected that the preliminary results obtained from the effort currently in progress will provide indications on what is the best way to go. Guidance from the Doctoral Consortium at that point of the development would also be very helpful for defining what methodology or set of methodologies should be deeper evaluated. However, regardless of this choice, it will be chosen at least one more case study to test and validate the proposed methodologies. This case study should be more complex and more realistic than the one used for the preliminary evaluations. It is expected that, since the author is employed by aircraft manufacturer EMBRAER, it will be possible to pick an interesting case study with real world application and availability of real measured data. Besides the capabilities and performance of the proposed methods, other points of interest for evaluation during the work are the limitations and robustness concerning some real world issues such as imprecision on system model.

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