Abstract

Management of Uncertainty in Sensor Validation, Sensor Fusion, and Diagnosis of Mechanical Systems Using Soft Computing Techniques

by

Kai Frank Goebel

Doctor of Philosophy in Mechanical Engineering

University of California at Berkeley

Professor Alice M. Agogino, Chair

The goal of this dissertation is to provide means to deal with uncertainty in complex sensor driven systems, in particular for sensor validation, sensor fusion, and diagnosis. These means come from probability theory, neural network theory, and fuzzy logic and are more generally termed as "soft computing" techniques. Our investigation considered systems which had to be controlled based on monitored sensor readings to allow corrective action in case of aberrations from a desired value. Since all sensor readings are always subject to a variety of noise conditions, such as Gaussian noise, bias, clutter, outliers, and non-symmetric noise distributions, the aim is to perform sensor validation and Ð in case of multiple sensor readings Ð sensor fusion. This dissertation provides means for fuzzy sensor validation and fusion. This approach was compared with a probabilistic method which is a Kalman filter based scheme assuming Gaussian noise distribution. While the fusion is performed for the probabilistic method in a Bayesian way, the fuzzy sensor validation and fusion approach uses non-symmetric validation regions in which sensors readings are assigned confidence values. Each sensor has its own dynamic validation curve which is shaped according to sensor characteristics. These characteristics can take into account the range, external factors affecting the sensor, reliability of the sensor, etc. The curves have its maximum value at the predicted value which is arrived at using fuzzy exponential weighted moving average time series predictor. Sensor readings have value 0 at the boundaries of the validation gate which is determined by the maximum possible change a system can undergo in one time sample. Since readings outside the gate are implausible, they are discarded. Readings closer towards the predicted value are rewarded with a higher confidence value. Fusion is performed using a weighted average of sensor readings and confidence values and the predicted value scaled by the operating condition. Each method performs best in the presence of certain types of noise and recommendations are made as to which approach is more appropriate under various conditions.

Another aspect of this dissertation is to provide a tool for diagnosis in the presence of vague symptoms. This is achieved though fuzzy abduction which can diagnose crisp as well as soft faults. This means that faults can be diagnosed if they occur to some degree. The proposed algorithm computes a closeness measure taking into account the distance from an observed symptom set to the modeled symptom set for all failure combinations. It then ranks the failure sets according to maximum closeness measure and minimum cover, i.e., number of faults. As an extension, a framework for fuzzy influence diagrams is provided which uses this closeness measure.

Several applications from extant systems show the feasibility of the approaches developed here. The first example aims at providing safety enhancement in intelligent vehicle highway systems. Here it is crucial to always provide a correct sensor value to ensure a safe ride of the passengers. It is shown how the sysstem recovers from bad sensor readings and how functional redundancy included in the fusion helps to improve the results. Furthermore, it is shown how fault diagnosis is performed on-line. The second example is to provide robust and optimal control in power plants. It is imperative to provide correct sensor values to be able to distinguish between system and sensor failure and to prevent unwarranted shutdowns. Through the inclusion into the fusion algorithm of system variables having a functional relationship to the reading of interest, the system is able to exploit this functional redundancy to perform properly in the presence of multiple simultaneous sensor failure. Lastly, an example from manufacturing shows how the neural network tools provided allow for improved decision making for optimal tool exchange in a high speed milling machine environment by monitoring the degree of tool wear on-line.