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An intelligent sensing system for corrosion diagnosis and prognosis

I.S. Cole[1], P. Corrigan[1], W. Ganther[1], C.J. Lewis[2], T. Muster[1], D.C. Price[2], D.A. Scott[2]
CSIRO Materials Science & Engineering,
[1]Clayton, Victoria
[2]Lindfield, NSW

Networks of sensors that employ computational elements to intelligently process the sensed data to deduce or infer information about the state of the sensed system represent an important class of cyber-physical systems. This and a companion paper describe two distinctly different types of intelligent sensing systems, both of which have been developed to monitor aspects of the state (health) of aircraft or space vehicles. This paper describes a sensing system whose purpose is to monitor the presence and severity of corrosion, particularly in locations that cannot be directly accessed by sensors (e.g. crevices, fastener holes), and to develop prognostic models to allow forward estimates of damage development to be made. A further requirement is to use the sensor data to estimate corrosion damage in regions of the structure that are not directly sensed. Corrosion (and other forms of environmental degradation of materials) generally occurs slowly, allowing damage development to be tracked over extended periods of time and related to microclimatic drivers. The companion paper, on the other hand, is concerned with damage that develops very rapidly – caused by impacts – so different sensing and computational approaches are required.

Corrosion occurs through electrochemical processes at the surfaces of metals when moisture and dissolved salts are present. In complex structures such as aircraft it generally occurs fastest in places that are difficult to inspect and where it is difficult or impossible to locate sensors, such as in crevices and fastener holes, since such locations tend to retain moisture for long periods of time. Because of these difficulties, corrosion in aircraft is universally monitored by visual inspection at periodic intervals, which is a time-consuming and expensive process that can sometimes actually cause acceleration of corrosion development (e.g. if a seal is opened for inspection and incorrectly re-sealed). The approach adopted in this work is not based on direct sensing of corrosion damage in the structure, but on inferring the presence and development of corrosion by monitoring the microclimatic quantities that promote corrosion. The physical basis of the inference procedures and the models on which they are based will be outlined below.

Inference requires the use of prior knowledge and/or assumptions of relationships between quantities or variables, often expressed as models. This work utilises modelling at two distinguishable levels, and the types of model used are quite different.

i) A model to infer the instantaneous corrosion rate from the values of the measured microclimate variables. This model is a statistical (data-driven) model based on and constrained by known physical processes of corrosion - it is thus a novel hybrid approach to modelling corrosion. This type of model is used because of the complexity of the underlying processes of corrosion: physical models lack the predictive accuracy needed. The model for corrosion at a particular location is built from the sensed data at that location. It is constructed from the recent time series data from the sensors, and may change with time to reflect time-dependent changes in the dominant corrosion processes.

ii) Models to relate the microclimate at locations that do not contain sensors to the measured microclimate at sensed locations. These are generally physical models of air, heat and moisture transport between different locations within the structure.

The ability to predict the future development of corrosion damage (prognosis) is an important requirement of the system to enable maintenance planning. Prognosis requires predictions of future conditions, and it utilises aspects of both types i) and ii) models. Information about expected future usage patterns may be used to project the external environments the aircraft will encounter, and thermal and air transport models are then applied to estimate the resulting local microclimates. Models of type i) are then used to estimate future corrosion rates.

The overall aim for the system is to have a relatively sparse network of sensing nodes in a structure such as an aircraft, located at known corrosion "hot spots", and to use the information they provide to predict the likelihood of corrosion damage throughout the aircraft. The proposed system architecture is a central network of intelligent local sensing nodes (or agents). The local nodes will acquire and process their own sensor data, and may construct a local corrosion model. The central node will maintain global structural and operational data, will construct the environmental transport models and will be the home of "virtual nodes" that calculate corrosion damage at un-sensed locations within the aircraft. It will carry out the prognostic calculations and maintain the user interface and reporting functions.

Current state of development

While research into various aspects of the system is continuing, prototype systems have been flown on both commercial and defence aircraft to verify the feasibility of the approach and to acquire data to inform model development. At this stage the prototype sensing nodes simply log microclimate and corrosion data for off-line analysis – data downloads and analysis occur at roughly six-monthly intervals. The test program is being expanded to include different aircraft types operating in a broader range of environments. Further details and results will be shown in the full paper.