**Robust Design Optimisation of Dynamical Space Systems**

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1. **Abstract**

In this paper we present a novel approach to the optimisation of complex systems affected by epistemic uncertainty when system and uncertainty evolve dynamically with time. Epistemic uncertainty is due to a lack of knowledge or to incomplete information. This type of uncertainty is typical in early design phases, when multiple experts are providing different opinions, models are low fidelity or in the case of poor quality and incomplete data.

Evidence Theory provides a valid mathematical tool to model this type of uncertainty [1,2,3] though it is computationally expensive and difficult to handle. In this paper we propose a new modelling approach that uses Evidence Theory to capture epistemic uncertainty and provide an efficient calculation of the quantities of interest. The new approach is called “Evidence Network Model” (ENM) and it was introduced in [4] and extended in [5] to model engineering systems that can be decomposed in a number of subsystems or functions. ENMs are undirected and connected graphs where each node is a sub-system and each link an information pathway. In this work, ENMs are extended to include time dependent uncertainty and a time varying performance criterion.

In particular, in this work we consider the case in which the behaviour of some components of the system is affected by time during the operational life (failure rate, performance degradation, function degradation, etc.). The goal is to obtain a solution that is robust with respect to performance variability and is resilient against possible partial failures of one or more components.

The computational method proposed in this paper exploits the nature of ENM and decomposes the problem into subproblems of smaller complexity, under suitable assumptions. The overall quantification of robustness and resilience is then derived from an assembly process of all the subproblems. This decomposition method, called h-decomposition, reduces the computational cost and makes the quantification of uncertainty in complex systems affordable for a range of real-world applications.

A simple example demonstrates that ENMs are a valid tool for the preliminary design of complex space systems that are affected by time varying epistemic uncertainty. The method is here applied to a resource allocation problem where the goal is to optimally position components within a spacecraft [6]. The objective function is the minimisation of the moment of inertia relative to the vertical axis and the way the subsystems and components are allocated influences the centre of gravity of the whole system. The mass and size of each component is affected by uncertainty in system design parameters and system degradation. A failure rate - function of time and affected by epistemic uncertainty- is used to quantify the performance degradation of the power system. The failure rate is then used to modify the number and type of cells of the solar panels and of the batteries. The variation of these parameters induces a change of the mass and size of the component and as a result the barycentre and moment of inertia of the whole system.

1. **References**

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