Abstract

Constrained dynamic performance and control models of complex engineering systems can be represented in the form of a Differential Algebraic Equation (DAE) system. The high-index of this DAE system poses computational challenges. However, when successfully solved, this system can be used for prescribed path control, wherein an inverse simulation can be performed to know the system behavior prior to operation for desired output. In this work, high-index DAE regularization challenge is brought out, and its application illustrated with variety of case studies encompassing robotic car, gas turbine engine control system and Unmanned Aerial Vehicle (UAV). A method for performance prescription has been evolved. An important result linking path prescribed control to condition number of iteration Jacobian matrix has also been brought out.

In the first case a simple robotic car and its prescribed path control has been considered. It illustrates the concept of inverse simulation, index, high condition number Jacobian etc. Thereafter, mission simulation of UAV is considered. It is important to ascertain the feasibility of a trajectory in a mission. An algorithm has been developed for feasibility study of a trajectory of UAV using path prescribed optimal control through an inverse simulation method. This has been done under a Differential Algebraic Equations (DAE)/Inequalities (DAI) framework. The UAV model together with constraints is represented as a high-index DAE system. The trajectory that UAV shall follow is modelled as one of the constraint equations. The solution for the DAE system is obtained using variation of the alpha method that is capable of handling both equality and inequality constraints on system dynamics. The algorithm involves a direct numerical integration of a DAI formulation in a time stepping manner using Sequential Quadratic

Programming (SQP) solver that detects and satisfies active path constraints at each time step (mesh point). In this unique approach, the model and the constraints are always solved together. The method ensures stable solution at each time step, local minimum at each iteration of simulation and provides a regularised basis to the solver. Some typical UAV trajectories have also been simulated and demonstrated. This novel approach can be used for path planning of UAVs prior to design of actual control law for flight controls. Compared to other existing computationally intensive techniques, this approach is computationally simple, ensures continuous constraint satisfaction and provides a viable option for model predictive control of UAVs.

Obstacle avoidance forms an essential operational requirement for UAVs since they will need to operate in obstructed terrains engulfed in congested and weighed environments. Thus, the feasible path planning of unmanned vehicles is extended to obstacle avoidance and shortest path problem. The generated path shall not only be consistent with obstacles, weighed regions but also need to be within the physical and operational constraints of the UAV. As compared to existing approaches using highly simplified model of UAV or sensors, the proposed approach deals with a method that takes into account the complete dynamic model of UAV for arriving at a feasible safe path throughout. The parameterized path is prescribed as a constraint to the differential algebraic inequality system. The difficulty in following the prescribed path is reflected in the high condition number of Jacobian matrix. This high-index problem is solved using the alpha method combined with a SQP solver.

The third case study deals with gas turbine engine control problem. Modern day gas turbines are prime movers in land, air and sea. They have stringent performance requirements to meet the complex mission objectives. Optimal control strategies can help them meet their performance objectives more efficiently. A novel inverse simulation method for optimal control and system analysis studies using DAE/DAI technique is attempted in our work. The model together with safety constraints and performance specifications is represented and solved as a high-index DAI/DAE system.