MODEL BASED THERMAL MANAGEMENT THROUGH HEAT INJECTION AND REMOVAL

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ABSTRACT

Due to the ever-increasing packing density and precision requirement of the electronics industry, the thermal management issue has become a major challenge throughout the design, manufacturing, and operation of electronic devices. Thermal management mechanisms within the electronic devices, such as dynamic voltage and frequency scaling and thermal-aware task scheduling, have been extensively studied. In this thesis, we investigate two model based thermal management approaches: heat injection for active thermal growth regulation and heat removal with imposed heat flux.

In the electronics manufacturing process, high speed motion and high positioning accuracy to sub-micron range are now frequently required. The thermal disturbance from the motors, however, can cause unwanted thermal expansion and distortion of the positioning system. The traditional compensation approach, based on the static mapping from the temperature measurements to the thermal displacements, suffers from drift of the mapping over time and does not utilize the motor motion information. We propose an active heating control scheme to compensate for transient motor heating, and investigate the associated model identification and reduction, sensor placement, actuator placement, and controller design problems. Using an identified linear time invariant (LTI) model, a Kalman filter is designed for temperature sensor placement and thermal displacements estimation. For thermal actuator placement, the system controllability grammian projected to the thermal displacement output space is evaluated to assess the candidate active heater locations. The linear-quadratic-Gaussian (LQG) design is adopted for real-time active heating control, which is demonstrated through the finite element simulation to be capable of regulating the locations of interest close to the preset target with a reasonable amount of active heating.

For the heat removal problem, we investigate refrigeration systems design with imposed heat flux. The conventional refrigeration systems, mostly designed for enclosure temperature regulation, cannot be used directly for imposed heat flux re-

moval applications because of the fundamentally different thermal boundary conditions and the associated critical heat flux (CHF) condition. We propose two different refrigeration systems for imposed heat flux removal, and develop the modeling and optimization methodology for quick assessment of various refrigeration system design options and evaluation of the design trade-offs. The two refrigeration systems proposed include a vapor compression cycle and a two-loop refrigeration system. Steady-state modeling of both cooling systems is presented and parametric studies are performed to evaluate the effects of various system inputs and design choices on the cooling system performances. The Pareto optimization is applied to find the optimal steady-state system operating conditions for given heat loads such that the system coefficient of performance (COP) is maximized while satisfying the CHF and other system operation constraints.