Bio-inspired Mobile Sensor Networks for Infrastructure Monitoring and Inspection

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Wireless sensing has been widely explored in recent years for structural monitoring and dynamic testing, due to its advantage of reducing instrumentation time and cost. Limitations of current wireless sensors have been identified in terms of power supply, communication bandwidth, communication range, computing power, etc. Wireless sensors that can provide high-precision vibration measurements still cost about a few hundred dollars each, which makes dense deployment prohibitive for large civil structures. To address the above challenges faced by current wireless sensor networks with static configurations, an alternative is to explore mobile sensor networks for structural health monitoring. Compared with static wireless sensors, mobile sensor networks offer flexible system architectures with adaptable spatial resolutions. The additional mobility helps alleviate the above limitations faced by static wireless sensors.

After millions of years of evolution, simple biological systems may illustrate far more superior performance than man-made sensing and actuation devices. In particular, bio-systems can shed light upon the development of future mobile sensor networks for the monitoring and inspection of infrastructure systems. On the mechanical side, insects and reptiles offer excellent examples for designing the adhesion and mobility of such mobile sensing nodes. For instance, in the past few years, geckos and other lizards have motivated significant research in climbing robots. Toe pads of a gecko foot consist of hundreds of thousands of microscopic setae. Each seta splits into hundreds of 200 nm wide spatular tips. Intermolecular forces provided by billions of spatular tips make geckos among the nature's best climbers. Robotic researchers are gaining initial success in employing polyurethane hair to mimic such intermolecular adhesion forces.

On the algorithmic side, structural damage detection algorithms may draw upon swarm intelligence shown by animal colonies. Swarm intelligence (SI) is the

property of a system whereby the collective behaviors of unsophisticated agents interacting locally result in coherent global functionalities. One recent advance in SI is the particle swarm optimization (PSO) algorithm that simulates the behaviors of foraging bird flocks. In PSO, the potential solutions, called particles, “fly” through the problem space by following the current optimum particles. PSO can be easily implemented in a distributed fashion using the embedded intelligence of mobile sensor nodes. Such a distributed and collaborative approach can be instrumental in high-resolution finite element model updating by the mobile sensor nodes.

As part of an explorative investigation in using mobile sensor networks for structural health monitoring, prototype mobile sensors have been developed using magnet-wheeled robots as the sensor carriers. The robots are capable of maneuvering in 3D civil structures built with ferromagnetic materials. The performance of the prototype mobile sensor network system has been validated with a laboratory structure. It is envisioned that in the near future, bio-inspired technologies will greatly advance infrastructure applications with mobile sensor networks.