A Paradigm Shift:
Composite/Smart Systems Innovation through Nanoscience, Life Sciences and IT Technologies

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The smart structures and smart systems have been one of the major contributions from the composite materials and structures community. With the advancement of the sensor and actuator technologies and control theory, the smart systems/structures have been developed and built "parasitically". Specifically, based on the control theory, sensors and actuators are placed at the strategic locations to manipulate the sub-elements in a system/structure for achieving more desirable, controllable and efficient system/structure, and oftentimes to arrive at structural health monitoring and self-healing capability. The success of this approach has been enormous and the applications are ranged from civil infrastructures to automobile and to aerospace systems.

However, the nature's smartness is not achieved "parasitically" but built-in "organically". For example, the bees and birds are substantially more agile, more efficient, more robust and more energy efficient than any their man-made counterpart. Therefore, the ultimate goal is to learn from the nature and build man-made systems where the smartness is "organically built-in". To achieve this vision, the smartness must be derived from the neurological-like sub-systems which are small, distributed, agile and responsive. The advancement in nanotechnology, information technology and life sciences has opened the doors for us to realize this vision.

Nanotechnology gives the capability for producing small and reliable sub-systems that can be integrated into a system/structure to achieve smartness. The advancement in nanotechnology processing has demonstrated that one can design and fabricate "built-in" functionalities (mechanical, thermal, electrical, magnetically and optical) by introducing nanoparticles or nanoelements into nanofibers the fundamental building blocks of a composite material/structure. With these functionalized nanofibers, distributed smart network can then be constructed and integrated into the systems of interest having sensing and actuation capability from mechanical, thermal, electrical, magnetic or optical stimulation and to arrive at the desired smartness. The knowledge from learning-from-natural will point-the-way to the material smartness development and to facilitate smart network development and design. The advancement in information technology will not only enable one to design smart network but also provide theoretical basis for systems control for their robustness and efficient operation. Since the organic "built-in" smart systems/structures are made of neuro-like networks, there are small, light weight, distributed, multifunctional and with extreme high efficiency in performance and in energy utilization. Additionally, because the smartness is not from the parasitic add-ons but from with-in organically integrated systems/structures, they are much more durable and long lasting.

The conventional composite materials are an integration of different material phases. Traditionally, these phases are being dealt with at marco-scale level and primarily for their mechanical performance with success. However, for the smart systems/structures discussed,

both nano-to-macroscale scale and other functionalities (mechanical, electrical, magnetic, thermal and optical) are major ingredients for designing sensing and actuation capabilities into the systems/structures. Therefore, conventional composite materials tools are inadequate and much advanced research is needed. For example, a multiscale (theory, analysis and experiment) theory coupled with experiment and simulation codes is essential to adequately address the integration issue resulting from the nano-to-micro systems/structures with mechanical, thermal, electrical, magnetic and optical functionalities.