

## **US-Japan Workshop on Bio-inspired Engineering of Next-Generation Sensors and Actuators**

Berkeley, California, November 12-13, 2011

The US-Japan Workshop on Bio-inspired Engineering of Next-Generation Sensors and Actuators was held on November 12 and 13, 2011 at the Bechtel Engineering Center on the University of California Berkeley campus. The workshop was supported by the National Science Foundation (NSF) and the Japan Science and Technology (JST) Agency. A total of 54 participants attended the workshop representing a multidisciplinary group of researchers from the fields of biology, chemistry, material science, and engineering (civil, mechanical, electrical and chemical). The workshop participants were focused on the development of a detailed roadmap for a trans-Pacific research program in bio-inspired engineering of common interest to the US and Japanese research communities. A particular emphasis was placed on the identification of research problems that would have the highest level of impact on societal quality of life. Toward that end, the workshop began with a series of keynote presentations from both Japanese and US participants followed by extensive breakout group discussions. A total of three breakout groups were formed with an equal number of participants from the US and Japan. The three breakout groups were given the same goal: define one or two grand challenge problems upon which future US-Japan research collaborations can be formed.

Working group participants identified five major interdisciplinary research themes that exemplify the spirit of the US-Japan Workshop. The multi-disciplinary grand challenge themes in the bio-inspired sensing and bio-inspired actuation (BSBA) area are summarized as follows:

- **Design of Multi-Level and Multi-Length Hierarchical Systems Inspired by Biology:** Biological systems employ hierarchical structures to achieve multifunctional system performance that far exceed the performance of current engineered systems. The grand challenge is to synthesize new fabrication methods that utilize and achieve hierarchical systems, utilize reverse engineering techniques to develop new tools, and integrate sensing and actuation technologies into those structures. The research challenges include integration and scalability of top-down and bottom-up fabrication methodologies, multi-dimensional fabrication principles that encode desirable properties at drastically different length scales, self-assembly methods for attaining precise spatial structures, arrangements, and functionalities, and comprehensive and realistic mathematical models and representations of biological systems and functionalities.
- **Teaching Bio-inspired Engineering:** To support the next-generation of BSBA researcher, the community should create education programs geared toward teaching engineers, biologists, chemists, and material scientists the principles and applications of bio-inspired design. For example, a 5-week summer program should be created for graduate students and post-doctorate researchers consisting of lessons, on-hand experiments and an extensive bio-inspired design project.
- **Bio-inspired Biochemical Engineering of Systems for Energy, Water, Food, Communications, and Medical Applications:** Biological systems thrive by inherent biochemical processes capable of controlling energy, material, and information interactions between components in the system. The grand challenge is to design robust, durable, self-regulating, and self-healing engineered systems with built-in artificial homeostasis, metabolic and enzymatic mechanisms. The research challenges include the incorporation of a heterogeneous network of evolving, adjustable, and adaptive multifunctional nodes

capable of direct energy transduction, storage, and utilization. Accomplishing this grand challenge will result in sustainable food, energy, and water supply.

- **Biologically-inspired Robustness: Self-sustaining Sensors and Actuators:** The grand challenge is to understand the mechanisms of self-renewal and self-repair in biological systems and to translate the knowledge towards designing a new generation of self-sustaining sensors and actuators. The vision is that the developed sensors will maintain its performance under uncontrolled and harsh environments. The research challenges include: developing techniques for recognizing damage in sensors and actuators that could then be used for self-repair and self-renewal; incorporating redundancy in the sensor and actuator design; developing new functional materials with feedback for diagnostics and prognostics; and developing sensors with energy sustainability.
- **BICEP: Biologically Inspired Control, Enhancement and Processing:** The grand challenge is to understand biological mechanisms of amplification, sensitivity, and selectivity in sensing and actuation and to translate these principles into developing integrated sensory and actuation systems with local feedback control. The research challenges include: identification and distinguishing between local and global sensory information under resource constraints (size, energy, speed, *etc*); incorporation of amplification and feedback in sensors and actuators using biomimetic processes, such as avalanche, cascade, *etc*; understanding and exploiting the role of noise and nonlinearity in biological sensory systems; and design of novel systems based on these bio-inspired principles. Fundamental research aimed towards the design of actuators based of ATP-inspired chemical energy processes, such as those found in sarcomere, is also proposed. Key technical challenges includes energy management in self-generation and delivery of energy, the formation of sarcomere-actuators based on self-assembly methods.

These grand challenge problems have the potential to build on the historical legacy of US-Japan collaboration to pioneer new sensing and actuation technologies based on inspiration of natural processes. Undoubtedly, a formal US-Japan research and education program based on these grand challenge problems would pay major dividends including improved public health, the development of cost-efficient manufacturing processes, the creation of green energy sources, and enhanced safety of civil infrastructure systems. Given this abundance of potential impact, the participants of the workshop unanimously make the following recommendations to NSF and JST:

- A self-reinforcing loop of discovery must be promoted by NSF and JST to form explicit linkages of intellectual discovery between biologists/chemists and engineers in both the US and Japan. Engineers have the potential to provide tools and processes that can drive new and paradigm-shifting discovery in the biological and chemical fields through sensors and actuators defined at biological length-scales. Similarly, biologists/chemists can provide the fundamental understanding of natural sensors and actuators that can lead to the formation of bio-inspired sensors and actuators that solve engineering problems.
- To establish a vibrant bio-inspired engineering research community working in close collaboration, NSF and JST should place a particular emphasis on a jointly-funded bilateral US-Japan cooperative research program centered on bio-inspired sensing and actuation. A priority should be given to BSBA research aimed toward rendering society resilient to natural and man-made disasters and to the betterment of human life.

- Given the high potential for broad-based impact, NSF and JST should prioritize university-industry collaborations that accelerate the transfer of bio-inspired sensing and actuation technologies from the laboratory to implementation in society.
- To address critical research needs and tackle the grand challenges in the BSBA area, high priority should be placed on training the next generation of high quality, interdisciplinary researchers who are equally knowledgeable in engineering (including sensing and actuation technologies) and biology/chemistry. The United States and Japan are strongly urged to create a paradigm-shift in academic programs to produce future students with cross-disciplinary bio-sensing and bio-actuation knowledge and skills. In particular, a Summer Student/Early-Career Faculty Research Institute program, jointly organized and held in Japan and the US in annual rotation, should be carefully planned and implemented.

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