PiezoMEMS Enabled mm to cm-Scale Robotics

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The growing reliance on autonomous systems in numerous commercial and defense related applications has stimulated significant research toward miniaturizing such systems. Small scale systems could offer a number of advantages over larger robots in many applications; including lower cost, portability, and a reduced logistical burden. Millimeter-to-centimeter (mm-to-cm) scale robotic systems based on highly integrated microelectronics and micro-electromechanical systems (MEMS) could offer unique benefits and attributes for small-scale autonomous systems. Millimeterscale systems offer strong potential in terms of extreme low-observability and location accessibility. Moreover, the relevant manufacturing technologies, like MEMS and microelectronics, offer great potential for achieving integrated multifunctionality at unit costs that can enable the deployment of large and more capable heterogeneous networks of robots. This extreme scale for robotics will naturally constrain the realizable system capabilities significantly.

Numerous technical challenges must be overcome to realize this potential. For example, there are significant difficulties in achieving mobility performance comparable to biological examples while preserving nontrivial load bearing capability. Significant levels of integration of dissimilar technologies must be accomplished to exploit the advantages offered by MEMS and microelectronics to meet the needs of the various robotic subsystem functional requirements. MEMS offers the following advantages: high density integration, minimum structural feature sizes, cost and repeatability advantages due to batch manufacturing, and limited assembly requirements. Piezoelectricity provides highly efficient electromechanical transduction and the capability for large force and displacement actuation. Furthermore, piezoelectric MEMS (PiezoMEMS) especially using lead zirconate titanate (PZT) thin films are typically operated at very low voltages that mitigate the challenges posed by small scale power conversion.

In our current research, a notional mm-to-cm scale robotic system based on PiezoMEMS and highly integrated microelectronics is depicted in Figure 1. In Figure 1a, everything visible except the translucent chips would be manufactured in a monolithic PiezoMEMS process that would provide at a minimum, all of the necessary components like joints and linkages, for a mobile system. The translucent chips represent the other requisite subsystems like power or control that are necessary for a complete platform. The entire system could be comprised of a few individual chips, manufactured in their own performance and cost optimal processes, reduced in substrate thickness, and simply assembled with standard integrated circuit packaging techniques. Examples of notional ground and air mobile platforms using such an approach are illustrated in Figure 1b.

The current fabrication process uses a highly versatile thin film PZT fabrication monolithically integrated with a multilayer copper process to realize initial demonstrations of feasibility of creating mm-to-cm scale robotic platforms. As an example, Figure 2a highlights research on enabling microflight using a combination of active PiezoMEMS actuators to create both the stroke and pitch mechanisms commonly observed in two-wing insects. Additionally, Figure 2b highlights an integrated leg actuator with copper structural features and three PiezoMEMS actuators to mimic a single degree-of-freedom motion version of a hip, knee, and ankle joint.

This presentation will focus on fabrication and electromechanical design of the actuation and mobility mechanisms.

Keywords: millimeter-scale robotics, autonomous systems, MEMS, PiezoMEMS

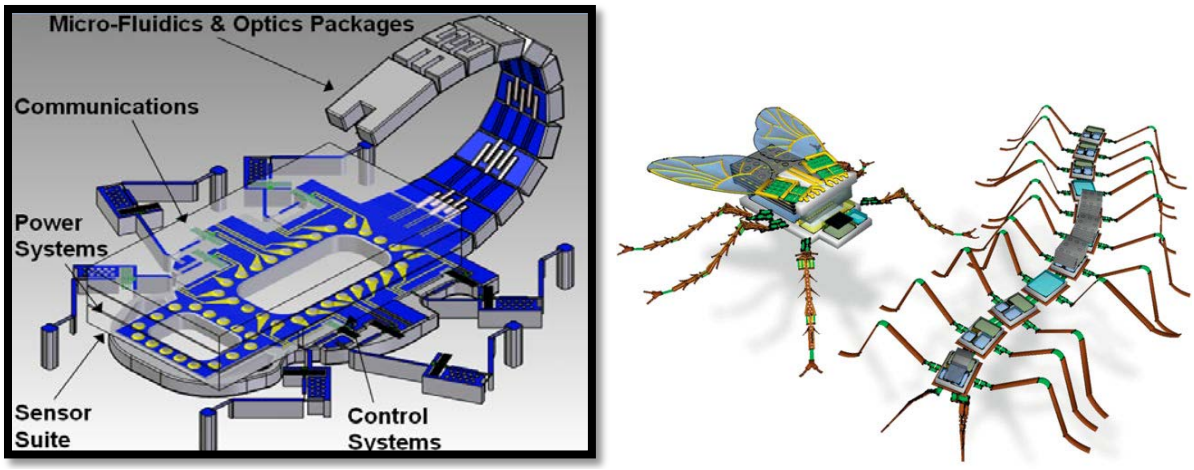

Figure 1. a) Notional mm-to-cm scale robotic systems based on a piezoelectric MEMS and a highly integrated microelectronics approach and b) illustration of notional ground and air mobile platforms.

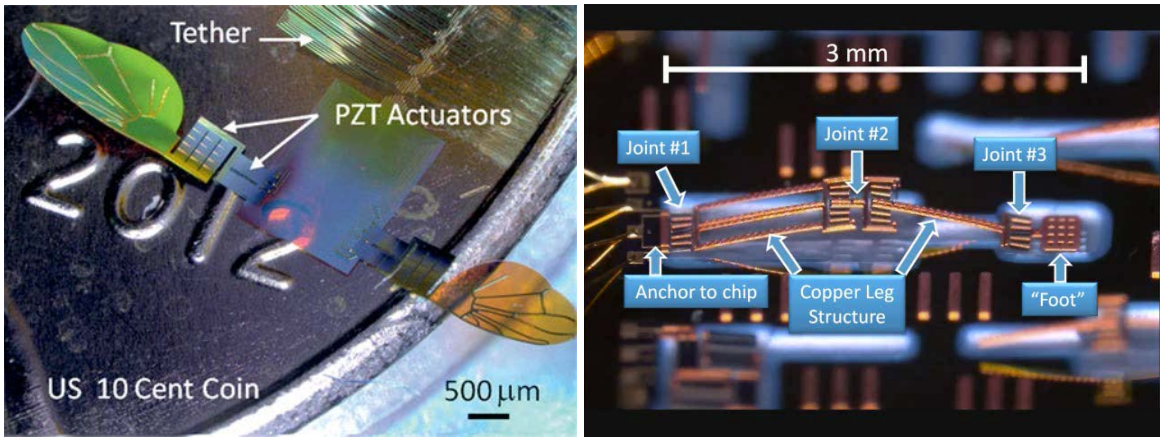

Figure 2. Examples of PiezoMEMS actuated microwings and a mm-scale robotic leg using PZT thin film actuators and multi-layer copper structural components