Resource-Constrained Micro-Robotic Control Systems

Key Terms:

Micro-Robotics, Bio-Inspired, Controls

Background:

Micro-robotic systems (< 1 cm in size) push all conventional boundaries of mechanics, computation, and integration. Medical devices, search and rescue missions, and smart infrastructure monitoring all stand to benefit enormously from these unique opportunities. However, autonomous systems on these scales will require extraordinarily optimized and integrated controls, using increasingly sparse electronic resources. Current robots address controls integration using a variety of approaches: incorporating accurate but inefficient controllers [1], employing simple but limited digital control schemes [2], using bio-inspired analog sensing and reacting systems [3], or eschewing closed-loop control entirely [4]. In these designs, mathematical models neglect to incorporate the entire system model, and thus have missed out on a host of **potential optimizations**. Additionally, the differences between these control approaches, as well as the advantages of combining them, have not yet been explored.

Motivation and Intellectual Merit:

Enormous potential exists in the applications of controllable micro-robots, yet few current micro-systems perform comparably to macro-scale robots. In the larger, successful bots, the challenge of combining sensing, control, and actuation in a whole integrated system has been addressed using traditional combinations of digital, analog, and mechanical components. In the mathematical identification of these systems, it is often reasonable to neglect the computational resources required and processing times of the controller [1]. This ideology introduces enormous challenges when scaling systems down to micro-size levels, since discrete integrated circuits and mechanical components add mass and volume.

As opposed to keeping control systems separate and isolated, I seek to address resource-constrained limitations by modeling and implementing a mix of **bio-inspired** and traditional control schemes as part of the whole, integrated robotic system. Different parts of the control system can be implemented digitally in software, in mechanics, or using analog circuits. Quantitatively analyzing the performance benefits and tradeoffs using these different control approaches, as well as combining a full range of digital, analog, and mechanical controls, could lead to extremely small sizes and high efficiencies. By mathematically describing the load on a traditional microprocessor when it computes a control law, its efficiency can be compared to analog or purely mechanical systems, and many previously-unseen optimizations could be made.

In performing **similar micro-controls research** at the University of Maryland, College Park, I have seen the limitations of assuming a perfectly efficient control algorithm. Throughout the process of developing the controls for a centimeter-scale robotic platform [2], I took advantage of opportunities to optimize across the hardware-to-software barrier. Similarly, in my computer science research at the Army Corps of Engineers Research Lab, I have seen the possibilities of incredibly efficient control algorithms in highly-integrated systems. This proposed research will employ this integrative approach in implementing the first true control autonomy in micro-scale robotics.

<u>Proposed Research:</u>

I propose to develop **a mathematical model** of the connection between the software, hardware, and mechanical aspects of micro-robotic control systems. I will then use this model to **prototype two autonomous micro-robots**, which will be the first examples of true micro-scale autonomous control. These will integrate legs as the primary means of locomotion.

First, after conducting a literature survey on all different aspects of this project, including controls, bio-inspired research, and efficiency of computer architectures, I will develop a general model for the planned optimizations. This model will describe the performance of each type of control in terms of reaction time, power usage, fabrication limitations, and other quantities. Modeling the interconnected aspects of a whole system will create a way to quantitatively compare analog, digital, and mechanical control approaches, as well as combinations therein, for a resource-constrained micro-robot.

After developing a basic model, I will refine it through multiple testing strategies. Primarily, I will fabricate larger robotic prototypes to **test the model's predictions**. A platform where different components could be swapped in and out would allow a direct comparison of bio-inspired, traditional, and combination designs against each other and against the model. By analyzing empirical results, the mathematical model can be adjusted and corrected.

Finally, I will **develop at least two legged micro-platforms** that utilize some final optimized control systems from the model. Since it is likely that some combination of previously-researched control systems will be the most efficient, these **final prototypes** will employ a range of optimized mechanical damping, analog components, and limited digital decision-making. These platforms can empirically show that a mixed bio-inspired controls approach can achieve the small scales and high efficiencies required for extremely constrained micro-robots. All of this will be verified in rigorous mathematical detail by the model.

<u>Broader Research Impacts:</u>

Controlling systems on micro-scales could lead to a revolution in many critically important fields of science and society. Robots built for medicine could implement these efficient controls to non-invasively repair tissue and save lives. Search and rescue missions would benefit from the assistance of tiny, autonomous, mobile sensors. Micro-robots could intelligently patrol building infrastructures, looking for failure points. By displaying this research in programs such as Maryland Robotics Day, during which I presented my current work this year, these proposed robots will help inspire future generations of engineers. Additionally, my work in diversity within engineering, and contact in national diversity organizations, provides channels to distribute this research to many marginalized communities within our society that can benefit from the increased access to learning, thereby increasing retention in engineering.

<u>References:</u>

[1] Nonami, K. "Modeling and control of unmanned small scale rotorcraft UAVs & MAVs." Autonomous Flying Robots. Tokyo: Springer. **2010**.

[2] Gateau, G.M.; Mirsky, D.; <u>Sabelhaus, A.P.</u>; Bergbreiter, S. "TinyTeRP: Tiny Terrestrial Robotic Platform with Simple Control." In Review at *IEEE ICRA 2012.* **2011**.

[3] Zufferey, Jean-Christophe. "Bio-inspired flying robots." Bio-inspired Flying Robots. Lausanne: EPFL Press. **2008.**

[4] Saranli, U.; Buehler, M., and Koditschek, D.E.; "RHex: A Simple and Highly Mobile Hexapod Robot." The International Journal of Robotics Research, 20.7. **2001.**