Bio-inspired robot design for legged locomotion

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I. LEARNING FROM BIOLOGY

Mobile robot designers are increasingly searching for inspirations and design cues from biological models. Although animals are great model for mobile robots, the process of implementation is often ambiguous. The direct implementation of biological features and morphology often becomes ineffective and misleads engineers due to various reasons. Firstly, engineers investigate animals to achieve a few particular functions whereas features of animals may serve for multiple functions or often remains unknown. Biological system are believed to evolves for many functions. Animals need to adapt to various natural environments, reproduce themselves, eat, digest, and grow. When it comes to robotics platforms, the requirements are much simpler and based on the applications. Secondly, difference between engineering building blocks and biological mechanisms prevent engineers from direct replication. Biological systems grows whereas mechanical systems are manufactured. Control system, actuators, structures, energy sources and mechanical properties in biological systems differ from artificial counterparts in a great extent.

II. DESIGN PROCESS

For effective implementation of ideas, a design process is introduced. The design process begins with seeking a function from biological systems. Often locomotive functions of animals become target function that engineers seek to achieve. Next step undergoes extensive observation of related behaviors in collaboration with biologists. Conversations with biologists are invaluable for identifying a range of animal examples and for pointers to the literature concerning their morphology and operation. Although the animal examples are generally impressive, it is important to remember that nature does not produce optimal solutions in any formal sense. Rather, nature works on the principle of what is “good enough” to afford a competitive advantage. Through comparative analysis and careful abstraction, hypothesizing principles follows. Sometimes, comparing homologous features among several species helps to remove bias from the interpretation. Through cautious observation and reasoning, we can extract hypotheses about the principles that govern the animals’ behavior and performance. The principles includes design principles behind detail features, simplified model of certain behaviors, and physical principles of a phenomenon. Hypothesized principles can be verified by biologists and engineering tools such as simulations and experiments. The next step is, selectively, to implement the principles in a robot. Since mechanical components differ from biological organisms, the principles need to be adapted in an artificial design space. The underlying functional principles need to be extracted from biology, digested by the designer and reincarnated. Modification of the principles through subsequent experimentations and analysis will ultimately provide refinement of the principles, and will accordingly improve the final design.
Fig. 3: Bio-inspired robot design based on principles from biological study.

Fig. 4: iSprawl is a small (0.3 Kg) autonomous, bio-inspired hexapod that runs at 15 body-lengths/second (2.3 m/s).

III. BIO-INSPIRED ROBOTS

Introduction of three successful bio-inspired robots exemplify the process: a) iSprawl is a cockroach-inspired hexapod with compliant, under-actuated legs and runs at 15 body-lengths per second, b) Spinybot is a hexapod that uses its toes with microspines to climb rough surfaces, including stucco, concrete and brick walls. Stickybot is a gecko-inspired quadruped that climbs smooth vertical surfaces using the world’s first directional adhesive, directional polymeric stalks (DPS) inspired by the directional setae and lamellae of the gecko. The design principles of Stickybot include hierarchical compliance, directional adhesion, and distributed force control.

IV. FUTURE WORK

The future research direction of the biomimetic robotics lab includes obtaining principles behind highly dynamic behaviors of the animals and implementing on robotic platforms. Extensive study on biological runners such as dogs and cheetahs will inspire the morphologic design of the galloping robot capable of the fast traverse on rough and unstructured terrains. Figure 5 shows a potential concept platform that enables research on hyper dynamic robotics. This new field of study will focus on quadrupeds’ behavior such as jumping, high speed running with gallop gait, and energy efficient running with trotting gait. Agile mobility of the robotic platform requires high acceleration capability with dynamic stability, jumping over large obstacles, and landing with the flexible body articulation. These highly dynamic behaviors involve multi-body dynamics of the dynamic control with tunable mechanical impedance. Based on the mechanical properties of actuators, the actuator allocation and actuation scheme can be optimized in order to achieve maximum performance. The first key thrusts include the development of high power density actuators with impedance control in pursuit of optimized force coordination of multi-degree of freedom legs and effective energy storage. Second research thrust seek to achieve a new control architecture that allows discrete impulse control of each stride to transition from one state to another and maintain a certain steady state. The final research thrust focuses on development of manufacturing techniques that allows lightweight resilient structure capable of dynamic locomotion.