AMAM 2005 - Research on Adaptive Motion in Animals and Machines

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Abstract

Research on adaptive motion in animals and machines is thriving. As illustrated by the numerous examples in these AMAM2005 proceedings, there are increasing numbers of fruitful collaborations between engineers and biologists, in all aspects related to adaptive motion, including body structures, materials, sensors, control mechanisms, and adaptive mechanisms. This article makes a brief review of, on one hand, how engineering techniques, in particular robots, can be useful to characterize and investigate animal motor control, and, on the other hand, how biological studies can help designing better machines.

1. Introduction

The abilities to efficiently move and coordinate their body are key and fascinating characteristics of animals. These abilities have been shaped by millions of years of evolutionary changes, and are often looked upon with awe by engineers. In particular, the skills to coordinate multiple degrees of freedom (DOFs), using compliant actuators (muscles and tendons), and massively parallel control (the central nervous system), give animals an agility and energy efficiency not yet replicated in man-made robots.

Understanding all the mechanisms that underly these fascinating abilities is a complex task since locomotion and movements are the results of complex interactions between the central nervous system, the body, and the environment. Studying individual components (e.g. the biomechanical properties of a muscle, or the rhythm generation of a central pattern generator) in isolation from the others is necessary, but not sufficient to decode the whole picture. Furthermore, a deep understanding often requires tools from multiple disciplines. One of the goals of the AMAM conferences is therefore to foster current collaborations and initiate new ones between multiple fields including zoology, ethology, neuroscience, evolutionary biology, biomechanics, mathematics, physics, and engineering. In particular, the AMAM conferences aim at demonstrating how robots and numerical simulations can be used as tools for biological studies, and how biological inspiration can help designing novel robot structures and controllers.

In the next sections, we first make a brief overview of different studies of adaptive motion included in the AMAM2005 proceedings (Section 2.). We then discuss biologically inspired robots (Section 3.) and present, on one hand how animals can be used as a source of inspiration for robotics (Section 3.1.), and on the other hand, how robotics can help animal studies (Section 3.2.). We finish the article with a short conclusion.

2. Studies of adaptive motion

In addition to projects involving biologically inspired robots (see next sections), the AMAM2005 proceedings include multiple studies of animal adaptive motion. The studies include zoological and evolutionary considerations (contribution by Fischer), studies of muscle properties (Schilling), kinematic and biomechanical studies (Schablowski, Heliot, Geyer, Ogihara, Lilje, Rummel, Schmidt, Seyfarth, Stepanik, Behn, Ilg, Wagner), various numerical models (Huq, Nishii, Hass, Kim, Senda, Otahal), tools for kinematic data processing (Zakotnik), studies of motor control (Grillner, Sunderland), and EMG recordings (Arnold, Ritzmann).

These studies give novel insights into the functioning of animals, and also provide new ideas for designing robots. For instance, the X-ray studies of tetrapod bone structures by Fischer's group have been instrumental in helping the design of the compliant quadruped robot Tekken in Kimura's group. Similarly, the decoding of vertebrate central pattern generators (CPGs) in Grillner's group have led to a new control paradigm based on coupled oscillators for legged robots (see work by Aoi, Buchli, Hioki, Kimura, Righetti, Roy, Veskos, for instance).

3. Biologically inspired robots

Inspiration from biology has led to a large variety of robots: swimming robots, snake robots, quadruped robots, hexapod robots, octopod robots, humanoid robots, brachiating robots, hopping robots, climbing robots, and flying robots. These robots have been constructed for a variety of different purposes: for instance, to solve a particular problem for a given application, to test hypotheses on the corresponding biological system, to serve as a proof of concept, for entertainment, for student projects, to demonstrate some new technologies, *etc*. But directly or indirectly, all these projects to some extent contribute to demonstrate how engineering techniques can be useful to characterize and investigate animal motor control, and how biological studies can help designing better machines.

3.1. Animals as sources of inspiration for building robots

Mimicking biological systems should not be an aim *per se* for engineers, and many useful engineering developments have little to do with biology (the use of metals, wheels, or rockets come to mind). In addition, animals are the result of a "messy" evolutionary process and of modifications of previous systems under multiple constraints, the main ones being to remain viable at all stages in development and the ability to reproduce. This evolutionary heritage means that the organization of animals is probably more complex and messy than if they had been engineered from scratch. Nevertheless, in terms of agile movements and locomotion, especially in complex terrains, it is clear that many animals outperform current technologies, and that inspiration from biology can therefore lead to technological advances.

The 2005 edition of the AMAM conference presents multiple interesting examples of bio-inspired technologies. These range from new types of sensors such as whiskers and antennas (see contributions by Kim, Goerke, Lange), muscle-like actuators (Radojicic, Hosoda, Kerscher), other contractile systems (Knoblauch), robotic arms and hands (Gomez, Klug, Bloban), biped and humanoid robots (Aoi, Hosoda, Geng, Behnke), quadruped and more legged robots (Tsujita, Buehler, Fumiya, Palis, Albiez, Schmucker, Kimura, Spenneberg), bouncing robots (Sprowitz), robotic worms (Menciassi, Steigenberger), amoebic robots (Ishiguro), and CPG and other control models (Righetti, Buchli, Cichocki, Hioki, Kiriazov, Schneider, Yamamoto, Buckley, Goerke, Henne, Ihme, Ponulak, Roy, Scott, Sisbot, Tellez, Veskos, Miglino, Osuka, Williams, Stelzer).

Many of these projects are driven by the desire to go beyond traditional mobile robotics, and to approach the agility and energy efficiencies of animals. Traditional mobile robotics is characterized by limited numbers of degrees of freedom (e.g. wheels rather than limbs), stiff structures and joints, limited natural dynamics (robots have often high gear ratios), and relatively few sensors. These choices are motivated by mechanical considerations (robots with few degrees of freedom are cheaper and easier to construct) and control considerations (e.g. it is much easier to measure states and to predict the effect of a motor command with a stiff robot compared to a robot that has visco-elastic properties). However these design choices make it difficult to reach the agility and energy efficiencies of animals.

In terms of energy efficiency, for instance, passive walkers and minimally actuated biped robots that use pendulum properties of human legs have demonstrated that walking gaits can be obtained that use an order of magnitude less energy than traditional humanoid robots.

Similarly, replicating visco-elastic properties of animals can help designing robots such as the Rhex robot (see the contribution by Buehler) that can locomote over complex terrain while using very simple control algorithms, thanks to the self-stabilizing properties of the body. Rhex probably outperforms most wheeled or caterpillar-tracked robots for locomotion in rough outdoor terrain.

Underwater locomotion is another area where inspiration from biology can outperform traditional technologies. Swimming is more energy efficient and allows better control of direction than propeller- or jet-based propulsion. The tuna, for instance, can reach impressive swimming velocities, and has therefore motivated the construction of the MIT Tuna robot a decade ago.

3.2. Robots as tools to understand animals

Robots can provide very useful tools to understand multiple aspects related to the production and control of locomotion and movements in animals.

For instance, robots can provide very useful tools for computational neuroscience. They indeed allow computational models to be tested as they are coupled to a real body and embedded in a real environment. In particular, this means that neural models can be tested within a complete sensing to acting loop. This is important since some aspects of locomotion might depend critically on the interaction with the environment, and would be difficult to study in isolated neural network models.

Dynamic simulators can be used to simulate the physics of the body and the environment, but one should realize they only provide a first approximation. Some interaction forces such as contact forces, friction forces, and hydrodynamic forces are extremely difficult to simulate correctly, especially for articulated bodies that move and change shape. Using a robot means that the physical laws do not need to be simulated, and reduces the risk of numerical artifacts. The same holds for perception: the use of real sensors (e.g. cameras,...) in a real environment eliminates the need to simulate the richness (in terms of noise, variations, energy spectrum,..) of sensory inputs due to the real world.

Another interesting aspect of using robots, is that they allow one to evaluate a computational model by comparing its results with biological data at multiple levels: from neuronal activity, to EMG recordings, to kinematic studies, and up to behavioral studies.

Finally, using robots forces one to aim at a comprehensive understanding of the functioning of a system. Failure is very visible with a robot (e.g. it will fall over, get stuck,...), and all the components of the control system have to be in place for the robot to work properly. For example, in the case of locomotion this requires correctly solving the problems of rhythm generation, coordination between degrees of freedom, control of balance, and modulation of speed and direction. This requirement to be comprehensive reduces the risks of wrongly assuming that some key computation is performed by another component than the one under study.

One should however not underestimate the difficulties in using robots for computational neuroscience. First of all, it is very difficult to correctly replicate the bio-mechanical properties of animal bodies, in particular their number of degrees of freedom, their mass distribution, and their visco-elastic properties. The benefits of not needing to simulate the physics is therefore counterbalanced by the fact that the robot might present an intrinsic dynamics which is significantly different from the modeled animal. Similarly, while some sensor modalities can correctly approximate biological ones, like vision and sound processing, others, like touch and proprioception, are yet far from being correctly replicated by current sensor technologies. Compared to simulations, robots present several additional constraints including (1) being less adjustable, (2) requiring a large overhead for construction and maintenance , and (3) being less amenable to extensive experiments. In conclusion, the pros and cons of using robots for computational neuroscience have to be carefully weighted.

4. Conclusion

Research in all areas related to adaptive motion in animals and machines is thriving. By carefully identifying how biology can contribute to robotics, and how robotics can contribute to biology, the two fields can successfully collaborate to deepen our understanding of animals and to produce novel robots, as illustrated by the numerous projects presented at AMAM2005. We hope that AMAM 2005 will lead to useful interactions, and be the starting point of new collaborations in this fascinating field of research.

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