UNC CHARLOTTE
The WILLIAM STATES LEE COLLEGE of ENGINEERING

Senior Design Project Description

Company Name	UNCC MEGR	Date Submitted	8/9/17
Project Title	Design and Optimization of an Elastically Compliant Swimming Robot Using Reinforcement Learning (UNCC_SWIM)	Planned Starting Semester	Fall 2017

Personnel

Typical teams will have 4-6 students, with engineering disciplines assigned based on the anticipated Scope of the Project. 250 hours are expected per person. Complete the following table if this information is known, otherwise the Senior Design Committee will develop based on the project scope:

Discipline	Number	Discipline	Number
Mechanical	2	Electrical	
Computer		Systems	
Other ( )			

Project Overview:

The project I have in mind concerns the design and testing of an underactuated aquatic robot that exploits a distribution of elastic compliance along its length to achieve a particular sort of fishlike propulsion. A novel aspect of the project is a plan to use reinforcement learning to optimize the distribution of elasticity relative to a certain performance metric. As a result of this plan, the "design" aspect of the project will include not only mechanical design but also the design of a machine learning system. A reasonable title for the project would be "Design and Optimization of an Elastically Compliant Swimming Robot Using Reinforcement Learning"

Initial Project Requirements:

With an increasing demand for robotic systems that can interact effectively with environments in which the dynamics may be unknown, or subject to modeling error or uncertainty, subfields of machine learning such as reinforcement learning are becoming more prominent in the field of robotics. Reinforcement learning provides a possible solution to these issues, allowing a robot to interact with its environment and learn over the course of these interactions. This is especially applicable in the case of biological organisms that navigate or traverse complex terrains or fluids. Certain environments may permit an analytical model of the dynamics of a system under consideration, but generally a robot's interaction with its environment can't be perfectly modeled, necessitating the research of solutions which can account for this uncertainty. Furthermore, the environment in which a robot moves may change appreciably throughout its interactions with it, making newer approaches, like robust reinforcement learning, attractive for determining optimal control strategies for systems like swimming robots which can experience sudden changes in the fluid through which it moves. Methods in reinforcement learning are typically used as a means of control or autonomy and while reinforcement learning is naturally attractive for controlling robots, we propose that it can also provide a possible solution to determining physical design parameters for systems which have dynamics that are difficult to model analytically. This project will involve developing a solution for determining physical design parameters for biologically inspired swimming robots which are optimal with respect to different performance objectives. The physical parameters in question could be passively compliant elements, like springs, the overall shape of the robot, or even location of a robot's center of mass. Take, for instance, a three-link swimming robot which moves through a fluid using a single control input on one joint and a spring on the other. We intend to use policy gradient methods to determine parameters like the spring constant necessary to achieve specific performance objectives. We propose that a focus on developing computational tools that use policy gradient methods in reinforcement learning can lend themselves to determining design parameters. Authors in [2] use policy gradient methods as a means of hitting a ball with an anthropomorphic arm, 1 but as of yet, no application of these methods to determining physical design parameters for a robot is known.

Expected Deliverables/Results:

Goals

2.1 Design Optimization -The students will ultimately be tasked with the research and implementation of methods which can yield optimal physical design parameters for biologically inspired swimming systems. Through the use of reinforcement learning, optimization methods, and simulation, it is expected that extracting these kinds of physical parameters can aid in the design and development of robotic systems for which the dynamics are unknown, or only partially known. The primary goals for this project are the development of computational tools based on policy gradient methods that can produce physical design parameters corresponding to optimized performance objectives, and the implementation of such methods on biologically inspired swimming robots. The use of policy gradient methods in determining physical design parameters is, as far as the authors know, novel to the reinforcement learning and robotics community. Thus, contributions to both the robotics and reinforcement learning community are expected as a result of the research conducted during this project.

2.2 Control - We also want to emphasize a component of this project which will involve control of the robots being studied. A benefit of using reinforcement learning as a means of control is that it isn't necessary to have a model of the system under consideration. If a partial model is available, it's possible the system could exist in an environment that requires interactions which are difficult, if not impossible, to accurately model. We first propose an exploration and comparison of learned control strategies versus known strategies for simple swimming systems for which a model is known. We then expect to further extend reinforcement learning as a means of control for complex systems that exhibit modeling uncertainty. Robust reinforcement learning provides a possible means of dealing with this uncertainty. The authors in [1] use a simple example to illustrate that a robust reinforcement learning controller is robust to changes in system parameters.

Fall 2017 - The intended format for the execution of the proposed project is as follows. The fall 2017 semester will focus heavily on extending the student's understanding of policy gradient methods in reinforcement learning for robotic sys- 2 tems while emphasizing future implementation on biologically inspired swimming robots. In parallel, the students may find it necessary to become familiar with using/developing physics-based simulation environments for modeling the locomotion of swimming bodies. Accurate physics-based simulators, that cater in particular to the simulation of deforming bodies which locomote through a fluid, are non-trivial to develop and thus will require the students to become familiar with numerical methods for fluid dynamics. It is expected that students will rely on already existing computational fluid dynamics tools, but extend them to accommodate the design problem being considered in this project. Due to the nature by which reinforcement learning algorithms learn an optimal policy, that is by learning over multiple thousands of trials, the utilization of such simulation environments will be necessary to quickly learn a base policy that can then be tested for robustness on an actual robot. Naturally, comparisons of simulation and experiment will be made. At the end of this semester, we expect that students will have a working knowledge of policy gradient methods, will have worked collaboratively to develop computational solutions for determining physical design parameters and will have began implementation of these methods on swimming robots. Significant time will also be spent on the research of robust control methods and robust reinforcement learning for the control of biologically inspired swimming robots. In particular, comparisons of these two methods of control will be made.

Spring 2018 The students will then shift focus to actual implementation of successfully researched policy gradient methods and robust control methods on swimming robots. Such implementation will require the student to construct biologically inspired swimming robots efficiently. Lab research has led to a straightforward and reliable way of constructing swimming robots for the purposes of fundamental research concerning their dynamics. The construction of robots will adhere to established methods, but will likely require specific design adaptations depending on the physical design parameters or control methods being studied. In building swimming systems, the students will restrict studies to planar locomotion so as to facilitate quick and efficient implementation of researched methods.

Disposition of Deliverables at the End of the Project:

Deliver to mentor

List here any specific skills, requirements, knowledge needed or suggested (If none please state none):