The field of biomimetic robotics has attempted to solve many design and control problems in robotics by looking at nature for inspiration. Legged robots have been studied for use in dangerous environments where terrain traversal would be difficult for wheeled and tracked robots. Currently available quadruped platforms are prohibitively expensive for academic research; thus, it is typical to see a single platform shared between several laboratories across various universities due to cost, limiting the ability of researchers to experiment directly on the hardware. Modularization of the robot hardware and software minimizes manufacturing and maintenance costs typically associated with highly articulated robots, especially if the number of sensors per module are reduced to the minimum number necessary for control of the servomotors in the modules. This thesis addresses aspects of the design and control of a minimal sensing quadruped robot with optimization aided soft-sensing in terms of solutions to the following problems:

1) Low cost modularized quadruped robot platform and motor test platform: Due to the high power required to achieve legged motion with payloads, many prior designs have used compact hydraulics and intricate joints to improve performance. The proposed quadruped platform instead uses digitally controlled servo-motors with self-contained sensing and control that are used as the base components of actuation modules, connected by universal frame components. A motor test platform derived from the same base construction provides a stable mechanism to identify motor parameters for high quality simulation.

2) Integration of simulations into the control framework at a low level: Currently available robot frameworks are specialized for higher level control aspects and may introduce significant additional overhead during operation. A new low-level framework designed for use with an integrated simulation component was developed to improve overall performance while maintaining ease of use. Issues common to low cost systems are addressed in the framework to mitigate potential performance issues associated with such hardware.

3) Estimating robot state for high level control: Traditional locomotion planning methods require sensory information not available on a sensorless platform. Sensory estimation can often provide sufficiently close results to hardware sensors in the case that the sensory model is well understood, however the complex motions associated with quadruped robots makes this difficult. A soft-sensing approach using optimization can be used to provide sufficiently high-quality estimates even when the output is highly abstracted from the input.

This thesis will be divided into the following sections:

Chapter 1: An introduction to the motivations and goals for the thesis will be presented.
Chapter 2: The background of the current state of quadruped hardware, control frameworks, and simulation research will be explained in this chapter. Commercial, military, and research oriented quadruped hardware designs that influenced the modular quadruped design will be discussed. Robot simulation techniques that are applicable to real-time systems will also be introduced.
Chapter 3: The design of a modularized quadruped robot addressing the problem of a low-cost quadruped platform will be introduced and kinematic and payload specifications analyzed. The primary components and their physical and control properties will be discussed, with an emphasis on self-contained servomechanisms that comprise the core of actuation modules. This chapter will also discuss simplified test platforms used in identification and calibration of the control framework and simulation.

Chapter 4: This chapter will introduce a low-level control and simulation framework which can be used with low cost modularized robots. The chapter presents a solution to the problem of integrating simulation and control at a lower level. The core aspects, interactions, and API surface of the framework will be outlined, including the actuator, communications, platform, data recording, and simulation as well as their interactions and optimizations. Additional components of the framework that work in conjunction with the core components will be discussed, in particular the non-linear and meta-heuristic optimization methods developed to improve automation of system identification and develop a basis for alternative soft-sensing methods.

Chapter 5: This chapter will discuss the methodologies necessary to provide a high-fidelity simulation of the robot platform and its environment. Assumptions and simplifications used within the simulation method will be analyzed in terms of their effect on the problem of simulation fidelity and performance. Discussion of simulation stability as a limiting factor in performance and accuracy will introduces the need for stable joint models.

Chapter 6: This chapter will address the imperfect joint problem for low cost quadrupeds in terms of a traditional and a new approach. As the joint model is separated from the simulation itself, simulation independent models of the joints must be used. The traditional electromechanical model is introduced and analyzed in terms of accuracy and stability within the simulation environment. Next, a novel rigid body constraint based model for the simulation of internally controlled articulated robot modules is proposed which can reduce simulation instabilities at larger time-steps without requiring simulation specific non-physical damping or closed-form dynamic solutions. The analysis of these two methods in terms of the robot platforms is discussed and the performance improvement for the novel method is demonstrated.

Chapter 7: This chapter addresses the soft-sensing solutions to the environment and robot state sensing problem using the techniques described in the previous chapters. High fidelity simulations require significant tuning, and the preliminary identification problem for a modularized robot is addressed by means of meta-heuristic optimization of the models discussed in Chapter 5. Next, the soft-sensing problem is explained in terms of an optimization problem in a similar form to that of the identification problem, and currently available methods are introduced. An optimization based abstracted state estimation method is proposed and experimental results of the method are used to validate the method.

Chapter 8: This chapter concludes the thesis and provides additional discussions on the previous chapters in the context of additional problems in quadruped robotics.