Jurassic Chicken: An Avian Bipedal Robot

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Megan Grimm
Machine Intelligence Lab (MIL)
University of Florida
Email: megan@mil.ufl.edu

Dr. A. Antonio Arroyo
Director, MIL
University of Florida
Email: arroyo@mil.ufl.edu

Dr. Eric M. Schwartz
Assistant Director, MIL
University of Florida
Email: ems@mil.ufl.edu

Abstract

Jurassic Chicken is a whimsically dubbed Master's thesis research platform. Based on avian physiology rather than human, this biped robot will eventually use a neural network to provide the dynamic balance required for forward locomotion of an inherently unstable system.

Introduction

Given that humanoid robots have been a pervasive feature in both speculative and scientific media since the addition of the word "robot" into the American lexicon, it comes as no surprise that the bulk of research conducted on autonomous biped robotics uses a humanoid platform.

Humans, however, are not the sole example of successful bipeds. Biped dinosaurs like the *Dinonychus* (or "velociraptor") recently popularized by the *Jurassic Park* movies were agile, successful predators. Modern taxonomy provides us with examples in the *Ratite* family: large, flightless birds like *Struthio camelus*, the African ostrich.

It was decided, therefore, out of both curiosity and the desire to conduct research that was not simply a recapitulation of work already conducted at a number of laboratories, to base the structure of this biped robot on a *Ratite* skeleton rather than a human.

Background

Bipedal locomotion is one of the more challenging control problems in robotics. While it is possible to construct a platform that is statically stable, such platforms tend to be limited in their speed and flexibility. One such example is the Machine Intelligence Lab's "Orb" [1], a successful biped robot that achieved balance primarily by the use of very large feet in which the bulk of the robot's weight was concentrated. While Orb was able to walk forward and to turn away from obstacles by means of a shuffling gait, its speed and agility were limited.

Agility can be achieved by application of dynamic balancing, in which the robot is constantly falling and catching itself on the next forward stride. The control problem is therefore significantly more complicated than that encountered in static balance. Application of a neural network to handle the control problem is therefore quite appropriate here, given that the issue is to model appropriate compensatory reactions to perturbations in the robot's balance, based on weighted sensory input.

Similar research has, admittedly, been conducted at the MIT Leg Lab on the "Troody" [2] platform, which is based on a *troodon* dinosaur; however, it was not certain whether MIT's researchers have yet applied a neural network to the issue of controlling Troody's locomotion.

Theory

The bulk of research conducted on bipedal locomotion models a system with a massless leg of variable length (that variable representing the function of knee and ankle flexion and extension), allowing the platform to be modeled as a rigid body of fixed mass. This simplifies the calculations of force and torque required to precipitate motion in a given direction [4].

Accordingly, this platform was designed with minimal weight in the legs, instead concentrating the joint actuators in the body to provide a centralized rigid mass. The center of gravity could then be easily determined, and its placement shifted from between the feet for static stability outside the stable point to induce motion.

Platform

The Jurassic Chicken biped platform is based on the taxonomy of a *Ratite*, or flightless bird, rather than on a human.

The applicable differences between an avian and a human leg and hip, besides the obvious, are a drastically shortened femur on the part of the avian skeleton and a correspondingly lengthened foot and ankle; from the perspective of a human leg, the avian is walking on its toes. The pelvis of an avian skeleton is also drastically different from that of a human, being both narrower and longer and possessing an extended ischium, as seen in Figure 1 (image courtesy of the Ratite Encyclopedia [6]).

The result, in the final version of the Jurassic Chicken, will be to bring the

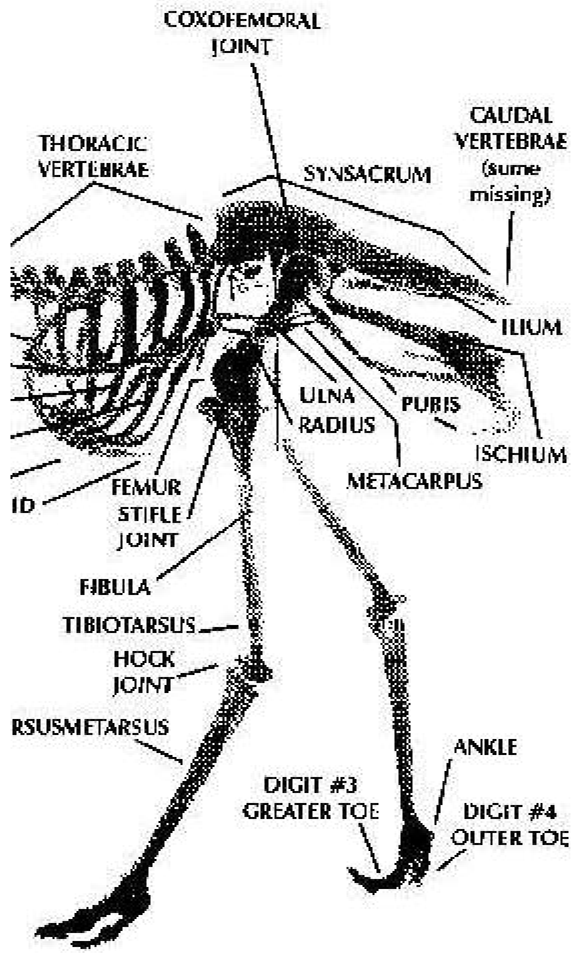

Fig. 1: Ostrich skeleton

center of gravity back behind the knees and before the ankles, an effect similar to that of a human standing with knees and ankles flexed. This is actually a very stable configuration and, furthermore, is less prone to overbalancing than a humanoid structure, especially given the extremely low mass of the legs relative to the mass of the body.

Figure 2 shows a rough sketch of the robot's general leg conformation. Because the final version has not been completed, actuator connections and specifics are omitted from the representation.

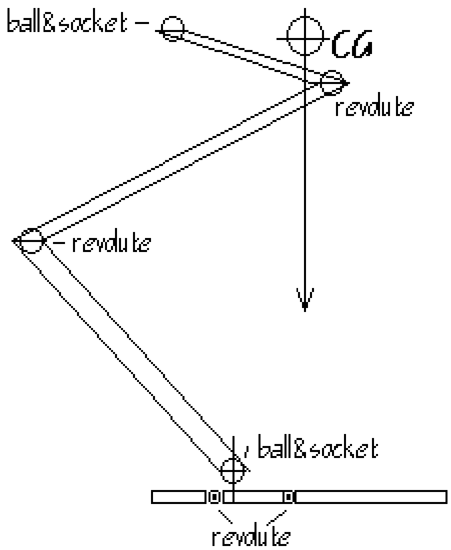

Fig. 2: Jurassic Chicken leg, side view

It has long been known that toes are an essential element of bipedal balancing. Accordingly, the Jurassic Chicken's foot includes three toes: two in front and one in the rear (Figure 3), thus providing compensatory reaction forces should the robot's balance shift too far either to the front or to the back. This arrangement also provides information regarding the side to which the robot is tilting.

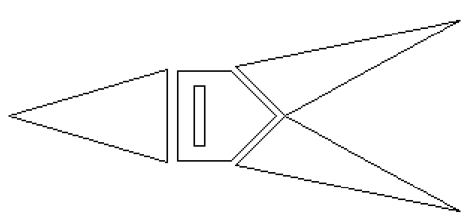

Fig. 3: Jurassic Chicken foot, top view

The platform's balance is to be accomplished via input from a two-axis accelerometer mounted on the body and force-sensing resistor films on each toe.

The accelerometer is an ADXL202 chip from Analog Devices [5]. Its outputs are duty-cycle-modulated signals that are proportional to the acceleration experienced in the two axes.

This acceleration can be calculated as follows:

$$\text{Acceleration (in g)} = \frac{\text{Duty cycle} - \text{duty cycle at 0g}}{\text{Duty cycle per g}}$$

The output can be PWM decoded by a microcontroller (e.g. the Motorola 68HC11E9 being used here) and used to determine whether the robot is tilting in either the x- or y-axis (the z-axis being parallel to the direction of the local gravitational force).

The platform also uses force feedback to determine the nature of contact of the feet with the ground surface. Force-sensitive resistor films (Force-Sensitive Resistors from Interlink Electronics [7]) will be placed on the underside of each toe, providing six ground-contact feedback sensors in total. In this way, the direction in which the robot is leaning can be determined, as can the relative force it subsequently applies in order to right itself.

Actuator control and sensor interface will be accomplished using the Motorola 68HC11E9 microprocessor. The microcontroller will be directed by a PC104 board running Linux; the final inclusion of this processing hardware (particularly its attendant hard drive and other peripherals) and its power supply will require that the final version of Jurassic Chicken be scaled up considerably from its current twelve-inch stature. However, a neural network cannot be supported on a 68HC11, and the ultimate goal of this project is to create a robot which is completely autonomous and untethered, thus requiring that all processing be done on-board.

Work to Date

Jurassic Chicken's legs have gone through several revisions to date.

The initial version involved a three-degree-of-freedom hip joint, with each joint actuated by a servo. The x- and y-axis servos were mounted at right angles to each other, controlling the axes of a miniature joystick (approximately 1 in^3); this assembly was then mounted in the body such that it could rotate with minimal friction and controlled by the z-axis servo mounted on the platform itself. A fourth servo controlled the knee, and two more controlled the pitch and roll of the ankle. All servos were mounted in the body itself, and controlled the joints by means of actuator rods (as in model aircraft applications).

This design proved to be prohibitively expensive, not only financially but also in terms of weight, space, and power. It was also inefficient and difficult to control.

The second version kept the 3 d.o.f. hip joint and the knee actuation, but moved to a passive ankle design. The passive ankle, rather than being actuated in two axes by servos, used a nylon ball-and-socket head joint. This provided a cone of free motion approximately 100 degrees in sweep.

As with the first version, this design also proved to be unwieldy and difficult to control efficiently.

The third version moved to shape-memory alloy pistons [8] for flexion and extension of the knee and ankle. This significantly reduced the weight and the complexity of the control problem.

Shape-memory alloys (SMAs) are ordinarily found in either wire or strip form, which can then be formed into springs, coils, and other shapes. When cool, the SMAs can be stretched, compressed, or otherwise deformed, but will return to their original dimensions with the application of heat (usually via the application of electric current). The pistons in question will shorten by 19 mm (0.75 inches) in 6 seconds, and can lift up to 450 grams (1 lb).

Unfortunately, the shape-memory alloy pistons have a recovery time of approximately seven seconds to return to their fully extended position, which provides for a maximum of two cycles per minute. A quicker response is vital in order for the robot to respond adequately to overbalancing.

Further, while they are excellent for contractive motion, they cannot provide the necessary thrust required for forward locomotion. Springs can be used to return them to the start position, but the propulsive thrust will still be lacking.

The current revision is returning to servos for flexion and extension of the knee and ankle joints, for lack of a better option. Further, the hip joint has been simplified to two degrees of freedom instead of three, removing the z-axis (vertical rotation) servo. This will prohibit the robot from turning fluidly, but it will save in weight, energy, and overall complexity.

The hip design has been further simplified and no longer uses the miniature joystick for x- and y-axis actuation; instead, the axes will be controlled directly by the servos.

Future Work

The current revision of the leg design needs to be completed and tested. Once an adequate leg has been designed and constructed, the sensors can be mounted and integrated with the microprocessor.

The neural network has yet to be designed or modeled. Research conducted to date, however, indicates that a network based on the Albus CMAC neural network [3] may be the most efficient option.

Conclusion

Jurassic Chicken is still a work in progress. Intensive effort will be required to see the project to completion; however, at the time of this paper being written, strides have been made in the design of the physical structure. It should be noted that designing a platform of this complexity is a not-inconsiderable challenge, particularly when the designer is an electrical rather than a mechanical engineer.

The concept of biologically-inspired robotics is hardly a new one, as is the application of a neural network to the problem of controlling the locomotion of a biologically-inspired robot. However, little research appears to have been done regarding the application of neural networks to the locomotion of an avian rather than humanoid robot. The fundamental mechanics and principles are essentially identical; however, the avian structure has certain mechanical characteristics that may prove interesting.

Bibliography

[1] Thakker, Purvesh. “Orb”. http://www.mil.ufl.edu/robots/orb.html April 1997.

[2] Dilworth, Peter. “Troody”. http://www.ai.mit.edu/people/chunks/chunks.html

[3] Miller, W. Thomas. “Real-Time Neural Network Control of a Biped Walking Robot”. IEEE Control Systems, Feb. 1994

[4] S. Kajita, T. Yamaura, A. Kobayashi. “Dynamic Walking Control of a Biped Robot Along a Potential Energy Conserving Orbit”. IEEE Transactions on Robotics and Automation, v. 8 no. 4, August 1992

[5] Weinburg, Harvey. “Using the ADXL202 with a Microcontroller.” http://www.analog.com/publications/whitepapers/products/newsletter/newsletter.html

[6] A. E. Marshall, B. A. Hopkins. “Ostrich Skeleton at Auburn University”. http://www.ratiterecords.com/sample4a.html

[7] Interlink Electronics http://www.interlinkelec.com

[8] Shape-Memory Alloy pistons Mondo-tronics, Inc.