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Leg Design For A Praying Mantis Robot

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Abstract

The praying mantis uses its front legs for locomotion, prey capture and feeding. Inspired by this dexterity, we began designing a hexapod robot that could use its front legs for both locomotion and manipulation. Our current work focuses on the middle and back legs of the robot. We designed a five degree of freedom leg, using a gimbal to form three intersecting axes of rotation at the hip to imitate a ball and socket joint. There is also a one degree of freedom knee, and an unpowered ankle joint. A key requirement for the design is to provide for standing postures in which the robot can support itself without putting any load on the leg servos. This will increase servo life span.

We simulated the leg by constructing a 3D model in SolidWorks, then importing that model into the Mirage simulator, part of the Tekkotsu robotics framework. A functioning prototype was then built using Robotis Dynamixel RX 64 servos. This was a geometrically simplified version of the original model, but it retained every motor capability of the original design. We tested the prototype using two types of pre specified motion sequences, with good results.

Introduction

The first prototype of the Chiara hexapod robot was built in 2008 (Atwood, and Berry, 2008; Touretzky, 2011; see Figure 1). Each leg achieved three degrees of freedom (DOF), using servos to power the movement. The Chiara also had a planar arm that extended horizontally and was capable of three DOF, with a gripper at the end. It had a webcam on a pan/tilt mount connected to a neck structure. Early in the design, an extra degree of freedom was added to the right front leg, allowing it to rotate upward and act like a claw. This proved useful for manipulating larger objects. A special gait was developed to allow the robot to walk on five legs instead of six.

The Chiara is a tabletop-scale mobile manipulator. Unlike human-scale robots that can perform household tasks such as loading a dishwasher, this class of robots is designed to operate in a confined area and only manipulate small objects. The small scale is important for educational applications where multiple robots must operate in the same lab or classroom. A Chiara with a specially designed gripper played chess at AAAI-10 (Anderson, Chernova, Dodds, Thomaz, and Touretzky, 2011).

Figure 1: *First prototype of the Chiara robot*

Experience with the Chiara revealed several areas where the design could be improved. Due to the design of the legs, the strain placed on the leg servos while the robot was in a standing position limited their lifespan, increasing the maintenance cost. In addition, the 24 Dynamixel AX-12+ servos used in the original design, although compact enough to maintain a relatively small footprint, did not provide sufficient power and maneuverability. Later revisions to the Chiara design used a mixture of AX-12 and more powerful RX-28 servos, but even more powerful options are avilable. When combined with a leg with greater reach and more degrees of freedom, these could potentially allow a tabletop-scale robot to negotiate uneven terrain. A third issue is that the Chiara's essentially planar arm (with the exception of a wrist pitch servo in the gripper) had limited reach and maneuverability, but a larger arm would have added too much weight and could have interfered with the front legs.

Figure 2: *The praying mantis insect serves as design inspiration for our robot. (Photo by J. Alves Gaspar via Wikimedia Commons.)*

Objective

We looked towards nature for design inspiration, analyzing proportions, behavior, locomotion and navigation. The insect world is full of small creatures with thin structured body frames that can accomplish complex tasks. Among the top predatory insects, the praying mantis distinguishes itself by its foreleg design. It not only uses these structures for locomotion, it relies exclusively on them for prey capture and feeding (Prete, 1999; see Figure 3). Prey items are caught and held securely with grasping, spiked forelegs. This allows the mantis to eat its prey while it is still alive. We are exploring whether a robot useful design features along these lines would be an effective platform for mobile manipulation.

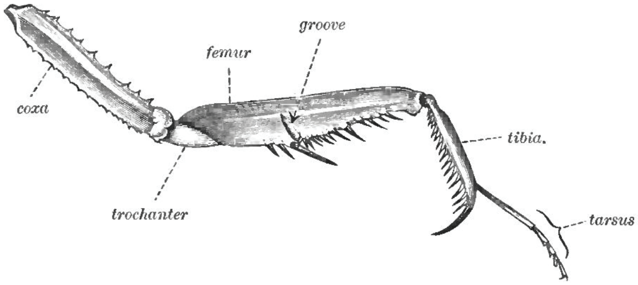

Figure 3: *Example of a typical mantis foreleg composition. A series of tubercles along the tibia and the apical claw near its tip, give the foreleg its grasp on its prey. The foreleg ends in a small tarsus which is used as a walking attachment (Photo by British Museum of Natural History via Wikimedia Commons.)*

The mantis is an attempt to improve on the Chiara in two significant ways. First, using larger legs should allow the body to be passively suspended below the middle and back legs with minimal power consumption so the servos will not heat up when the robot is standing idle. Second, using the front legs as part-time manipulators when the robot isn't walking eliminates the need for a separate arm.

Our goal is not to exactly mimic nature, but rather to identify useful design features that can be assimilated into a robot design in a way that is compatible with present technology. The servos available today cannot replicate the impressive strength-to-weight ratios of insects, but the gross architecture of the mantid may be worth emulating in a mobile manipulator.

Designing the Prototype

An in-depth analysis of the praying mantis insect was conducted. We interviewed an entomologist to learn about mantid anatomy and studied videos of mantis motion, especially its walking behavior. We also received advice from mechanical engineers about the design of our proposed leg structure. A cardboard model constructed during this phase demonstrated the direct translation of the proportion data, and illustrated the possibilities for both movement and static poses. This early mockup led us to mechanical ideas that would allow us to reproduce some of the insect’s motions.

The design was conceived in a virtual environment creating a three-dimensional model in SolidWorks. Concentrating the work on the middle and back legs, the design passed through five iterations (see Figure 4). The last version achieved a five degree of freedom leg, using a gimbal to form three intersecting axes of rotation at the hip that emulated a ball-and-socket joint. Consisting of a series of concentric rings each offering a particular degree of freedom (see Figure 5), the gimbal system provides greater flexibility than a fixed, static connection. Because each ring can pivot around one axis, any object attached to its center can face any direction at any time. The outermost ring produces the yaw axis which in our design is translated to the leg’s sweeping motion. The innermost ring deals with the roll axis used for the leg’s rotation. Rotation about the long axis of the femur allows the foot to be kept parallel to the ground plane while the body pitches up or down. It also allows the foot to adapt to slanted surfaces if the robot is walking on uneven terrain. Finally the

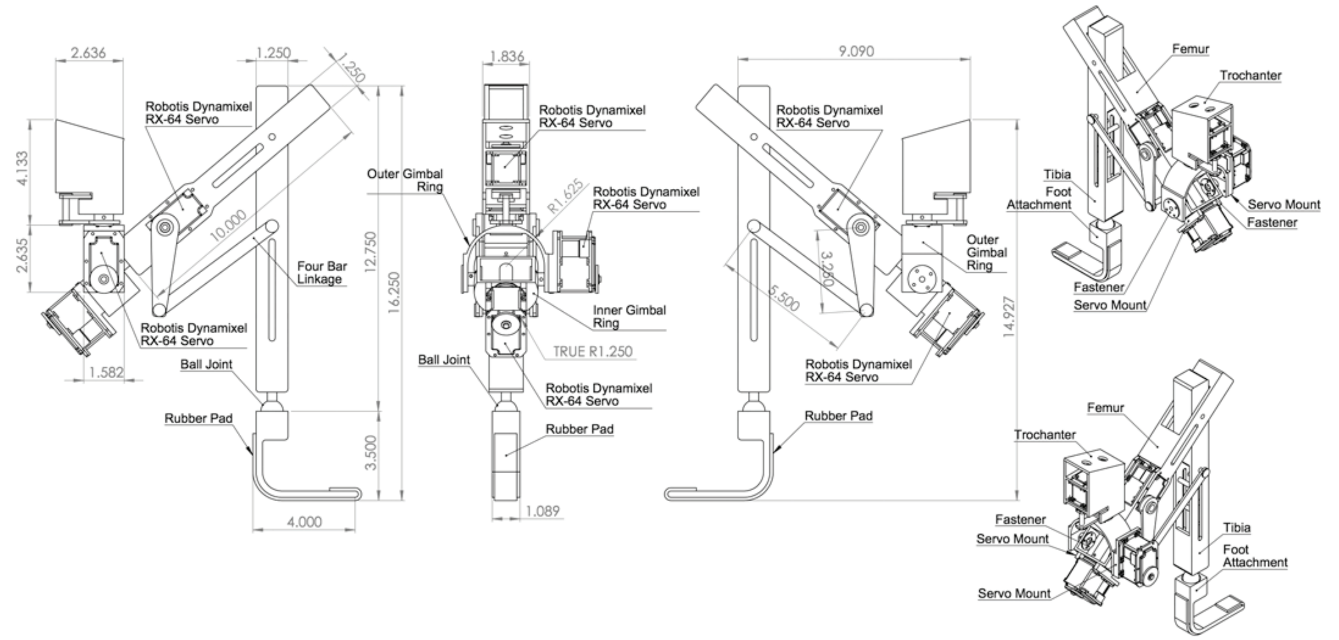

Figure 4: *Final design for the middle and back legs of the praying mantis robot. The leg is composed of four parts. From top to bottom they are: (1) The trochanter, which includes the outermost ring of the gimbal and controls the leg sweep motion. (2) The femur, which attaches to the innermost ring and controls the leg elevation and rotation. It also contains the servo that powers the four bar linkage. (3) The tibia, which connects to the femur to form the knee joint. Its movement is controlled through the four bar linkage system. And (4) the foot attachment, which incorporates rubber padding to improve surface contact. Its movement derives from a passive ball joint.*

middle ring produces the pitch axis translated to the leg's elevation.

The knee has a single degree of freedom. Rather than placing the knee servo at the knee joint, the joint is actuated indirectly, via a four-bar linkage, so the servo shaft doesn't bear the weight of the robot.

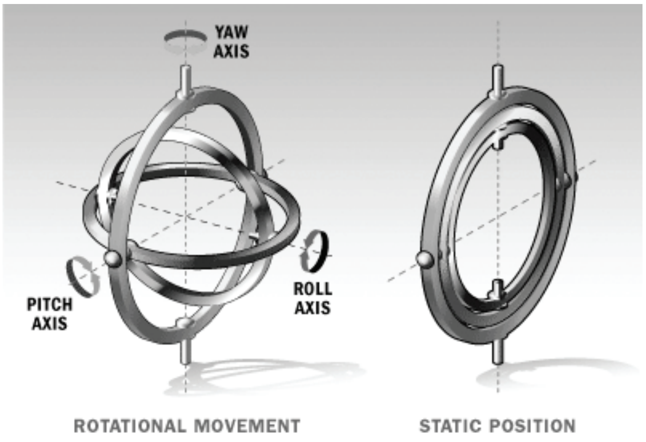

Figure 5: *Gimbal System. (Image by Jonathan Strickland via howstuffwork.)*

Finally the leg ends with an unpowered ball joint serving as an ankle, to provide some compliance at the foot.

Building the Prototype

We created a simplified version of our final leg design, also in SolidWorks, to facilitate rapid prototype construction. All mechanical ideas used in the design, like the gimbal and four-bar linkage systems, were adapted in terms of their geometric configuration. For example, instead of assembling the gimbal out of a series of nested rings each providing a single axis of rotation, we used square aluminum channels. Special attention was given to preserve the scale of the design and the use of the actual servo size specified.

This version was fabricated using acrylic and aluminum materials. Using 2x2 inch and 3x3 inch aluminum channel we produced the gimbal implementation. Four Robotis Dynamixel RX-64 servos powered the prototype's movements. A laser cutter, a milling machine, and a lathe were employed during construction. We accomplished the entire process in a two-week span (see Figure 6).

Tekkotsu Framework

The design was imported into the Mirage simulator, part of the Tekkotsu robotics framework (Tira-Thompson and Touretzky, 2011; Touretzky and Tira-Thompson, 2010). The software provides the means for describing the kinematic structure of the praying mantis robot and developing test programs for controlling it.

Kinematic information and configuration files were created that permitted us to maneuver the prototype in Tekkotsu. Simple behavior samples were coded to further test the design and constructed model's responsiveness to the framework. These predefined trials focused on outlining specific trajectories. The first tested the leg's ability to manipulate a cardboard box (see Figure 7). The second showed the flexibility of the four degrees of freedom design when circling a cylindrical object while keeping the foot parallel to the ground (see Figure 8). A video demonstration of these behaviors can be found at: <http://youtu.be/CRbGlZGwQak>

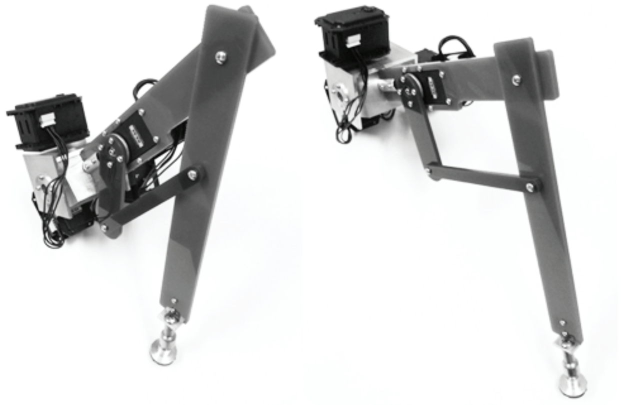

Figure 6: *Constructed leg prototype.*

Conclusion

Even though the gimbal-like-hip seemed to model a ball-and-socket joint to a certain extent, the angle of motion obtained was sometimes limited (see Figure 9). To reach a greater degree and retain a single point of intersection between axes, ample spacing between the gimbal parts should be allowed. The downside to this approach is a resulting oversized joint. An alternative approach, forgoing a single intersecting point could prove beneficial in gaining a broader angle of movement while preserving a small joint.

The prototype's implementation of an unpowered ankle, using a commercially acquired ball joint, also resulted in limited motion. There seem to be three possible solutions to this problem. The first, the use of a different commercially available part with the highest degree of movement possible. The second, to design a custom ball joint connection. The disadvantage here lies in the time and resources needed to design, built and assemble a custom-made unit. The third, to develop a powered ankle joint with the aid of servos less powerful than those used to power the hip-joint. This provides a higher degree of control and a small footprint when compared to the gimbal structure.

The four bar linkage together with the gimbal approach helped group the servos combined weight on a single point. This allowed for suitable weight distribution and eliminated unnecessary load on the knee joint. For future development, this approach is worth reusing on other areas of the robot design, like the arms and thorax-abdomen connection.

Although we intended the mantis to be the same size as the Chiara, our design is constrained both by the types of off-the-shelf servos presently available and the requirements of our gimbal structure. Robotis RX-64 servos were used to ensure that the legs will be strong enough to lift the mantis, but these servos are considerably larger than the AX-12s employed in the Chiara, which proved to be underpowered.

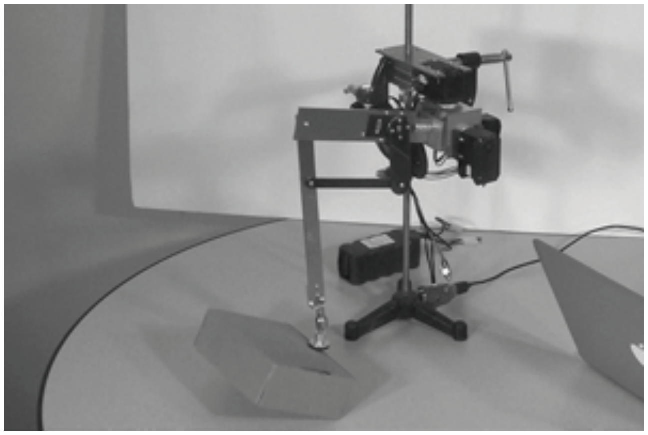

Figure 7: *Manipulation test of the prototype mantis leg. The task was to rotate a box from horizontal to vertical by applying pressure to the near edge, then push along the top edge to knock it horizontal again.*

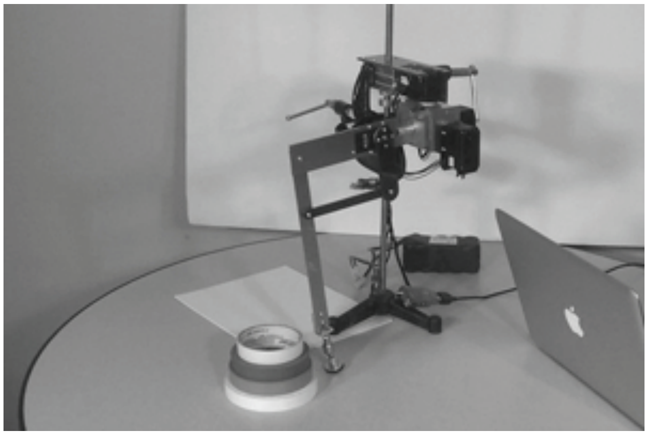

Figure 8: *Maneuvering test of the prototype mantis leg. The task was to circle a stack of tape rolls while keeping the foot at a constant height. After each circuit, the top roll was pushed off the stack, each in a different direction.*

It appears the initial mantis prototype will be roughly twice the size of a Chiara (see Figure 10). Our hope is that advances in servo technology will allow us to reduce the

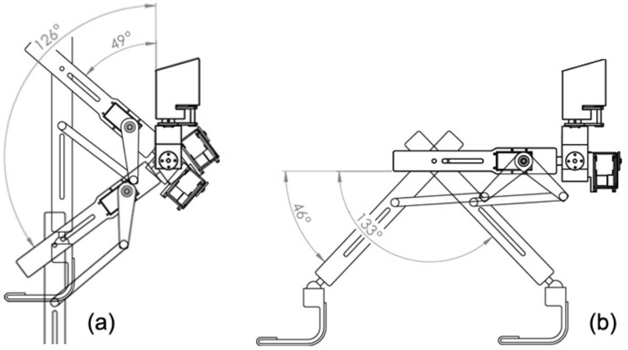

Figure 9: *Drawing (a) shows the maximun and minimun angle of elevation to be 126º and 49º respectively. This results in a leg elevation range of motion of 77º. Drawing (b) shows the maximun and minimun angle of knee extension to be 133º and 46º respectively, making the range of motion of 87º.*

size of later versions. We may also replace the gimbal with a more conventional structure that gives up the common point of rotation for the three hip axes in return for a more compact mechanism.

Future Work

The design and construction of the prototype leg constitute the first step towards a complete praying mantis robot. It gave us a greater understanding of the mechanical ideas employed, their reliability and direction of later revisions. It also stressed the need to research alternative materials strong enough to serve as the robot's structure, but flexible enough to ease the construction and assembly process.

With the leg prototype in place we can begin development of perhaps the most important part of the mantis robot, its front legs. The design has to accommodate both walking and grasping. It has to be strong enough to carry objects for some distance, and at times the weight of the robot. The design of the gripper will require the use of new strategies. The design could integrate a retracting mechanism which can toggle between different configurations for walking and grasping objects.

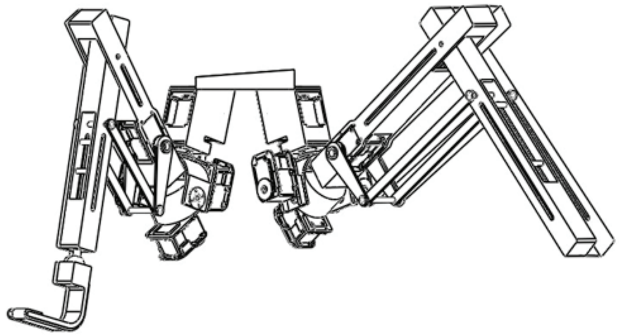

Figure 10: *Conceptual view of the middle and back leg assembly. When the robot is standing still, the body is suspended from the four legs with minimal power consumption.*

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References

Anderson, M. D., Chernova, S., Dodds, Z., Thomaz, A. L., and Touretzky, D. S. (2011) Report on the AAAI 2010 robot exhibition. AI Magazine, 32(3):109 118.

Atwood, T., and Berry, K. (2008) Chiara: Designed for computer science R&D. Robot Magazine, Nov Dec. 2008, pp. 12 13.

Prete, F. R., (1999) The Praying Mantids. 1st ed. The Johns Hopkins University Press, 1999.

Strickland, Jonathan (2012) howstuffworks, <http://science.howstuffworks.com/gimbal1.htm>, accessed February 15, 2012.

Tira Thompson, E. J., and Touretzky, D. S. (2011) The Tekkotsu robotics development environment. Proceedings of the IEEE International Conference on Robotics and Automation (ICRA 2011), Shanghai, China.

Touretzky, D. S., and Tira Thompson, E. J. (2010) The Tekkotsu "crew": Teaching robot programming at a higher level. Proceedings of EAAI 10: The First Symposium on Educational Advances in Artificial Intelligence, Atlanta, GA, July 13 14, 2010.

Touretzky, D. S., and Tira Thompson, E. J. (2011) Tekkotsu, <http://tekkotsu.org/>, accessed June July 2011.

Touretzky, D. S. (2011) Web site, <http://chiara robot.org/>, accessed June July 2011.