Chapter 4

Building Stiquito Controlled

Introduction

Legged robots are typically large, complex, and expensive. These factors have limited their use in research and education. Few laboratories can afford to construct 100-legged robot centipedes, or 100 six-legged robots to study emergent cooperative behavior; few universities can give each student in a robotics class his or her own walking robot.

A small, simple, and inexpensive six-legged robot that addresses these needs is described in this chapter. The robot is 75 millimeters long, 70 millimeters wide, 25 millimeters high and weighs 10 grams. When a circuit board is mounted on top of the robot, the assembly extends another 10 millimeters length-wise. The robot is constructed of fewer than 45 parts of which 12 move: six legs bend in response to six nitinol actuator wires. Nitinol wire, trade named Flexinol™, is an alloy of nickel and titanium that contracts when heated. It is also called shape-memory alloy. [1, 2] Most parts of the robot perform more than one electrical or mechanical function, but the design can be easily modified. For example, pairs of legs and actuators can be replicated to produce a mechanical centipede with flexible joints between leg segments.

The robot is intended for use as a research and educational platform to study computational sensors [3, 4], subsumption architectures [5], neural gait control [6], behavior of social insects [7], and machine vision [8]. The robot may be powered and controlled through a tether, but these instructions show how to assemble the robot to work autonomously with on-board power supply and electronics. It is capable of carrying up to 50 grams while walking at a speed of 3 to 10 centimeters per minute over slightly textured surfaces such as pressboard, short indoor-outdoor carpet, or poured concrete. The feet can be modified to walk on other surfaces. The robot walks when heat-activated nitinol actuator wires attached to the legs contract. The heat is generated by passing an electric current through the nitinol wire (See Figure 1). The legs can be actuated individually or in groups to yield tripod, caterpillar, or other gaits. The robot is named Stiquito after its larger and more complex predecessor, Sticky.

Insert Figure 1 here. Drawing of Stiquito's operation

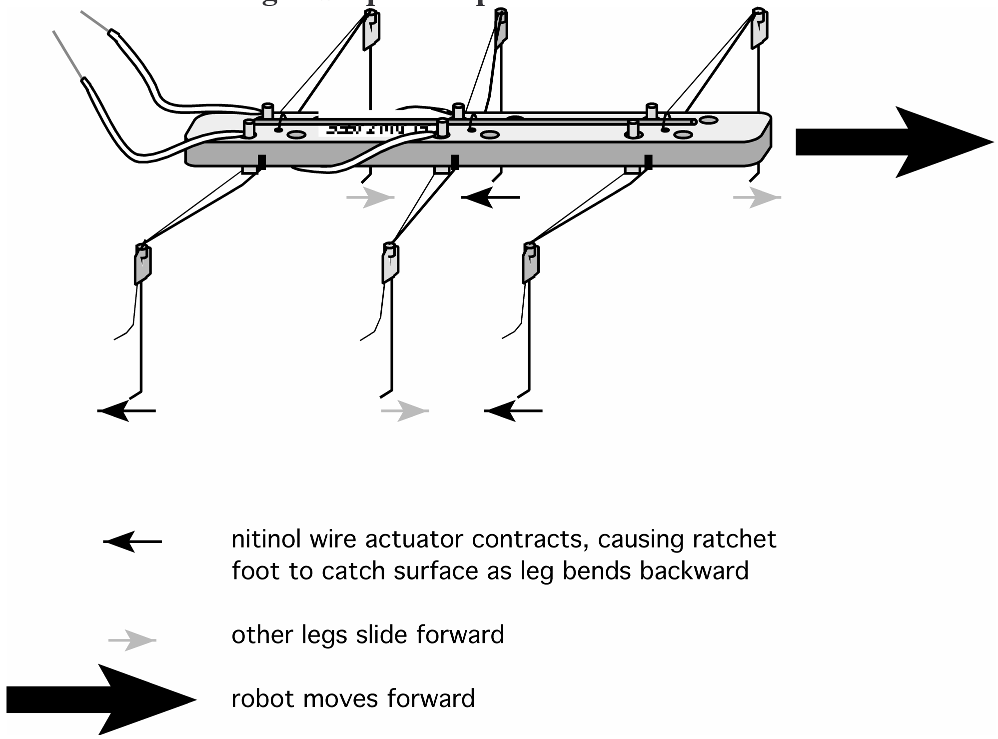


Figure 1: How the Stiquito robot walks (controller board not attached, for clarity of drawing)

The robot kit that is included in this book is a slight departure from the kit in the other Stiquito books, *Stiquito: Advanced Experiments* [9] and *Stiquito for Beginners* [10]. The kit in previous books was typically assembled without screws and included a manual controller. One would make these robots walk by applying voltage to the legs via the simple switches on the manual controller. While the parts in "Stiquito Controlled" kit is more complex because of the included microcontroller, its assembly has been simplified. There are fewer parts to cut and crimp. The time to assemble "Stiquito Controlled" is up to two hours, compared to up to six hours with previous kits.

Preparing To Build Stiquito

All materials and tools must be on hand before building the robot. This book contains all of the material needed to construct Stiquito. Check the material listed in the parts list (Table 1) to those in your kit. If anything is missing, contact `missingparts@stiquito.com`. Tools are not supplied with the kit.

Table 1: Parts list for the Stiquito Controlled robot

Photo	Amount	Part Number	Item
Table1a	1	ST-202	Stiquito Controller Board
Table1b	1	ST-100	Molded plastic Stiquito Body
Table1c	1 x 100 mm	K&S Eng. No. 100	1/16" outside diameter aluminum tubing
Table1d	5 x 100 mm	K&S Eng. No. 499	0.020" music wire
Table1e	600 mm	Dynalloy 0.004" Dia 70 C	0.004" (100um) nitinol wire (FlexinolTM)
Table1f	70 mm	Generic	20 AWG copper hook-up wire
Table1g	100 mm	Generic	30 AWG copper wire-wrap wire
Table1h	1 each	Generic	2 cell AAA battery holder
Table1i	1 each	Generic	320/360-grit sandpaper
Table1j	1 each	Generic	600-grit sandpaper
Table1k	7 each	Generic	Brass Screws, 0-80, 5/8" long
Table1l	13 each	Generic	Brass nuts, 0-80
Table1m	7 each	Generic	Brass washers, size 0

The tools needed to construct the robot are typically available in electronics supply stores or hobby shops. The following tools needed to build this robot:

Table 2: Tools needed to build the Stiquito Controlled robot

Photo	Item
Table2a	needlenose pliers
Table2b	wire cutters or sharp scissors
Table2c	small knife (X-Acto type)
Table2d	ruler graded in millimeters
Table2e	two AAA batteries
Table2f	volt-ohm meter (or use two AAA batteries and holder)
Table2g	soldering iron and solder
Table2h	(optional) hemostat

PRECAUTIONS

- Always follow the manufacturer's instructions when using a tool.
- Wear safety glasses to avoid injury to your eyes from broken tools, or pieces of metal that may fly away at high velocity as a result of bending or cutting. Be especially careful when bending or cutting music wire with wire cutters (the cut wire can be forced into your finger, for example).
- Use a piece of pressboard, dense cardboard, a cutting board, etc. to protect your work surface, if necessary.

Required Assembly Skills

A clear workspace and a relaxed frame of mind will be helpful during construction, especially when installing the nitinol actuators. Correct installation of the actuators will result in a robot that walks well, while a sloppy job will almost certainly lead to one that barely twitches.

Please remember that assembling Stiquito requires hobby-building skills. This section has been included for the benefit of those readers who have not assembled kits before. Practice the skills needed to build Stiquito before assembling the robot, using scrap plastic and thin wire. The kit has extra material in case of mistakes, but there is not enough with which to practice.

MEASURING: Following the “adage measure twice, cut once” will prevent most mistakes. Use any metric rule graded in millimeters.

CUTTING: Before cutting, check that your fingers are not in the way of your knife, and that a slip of the knife will not damage anything nearby. Direct the knife away from yourself to avoid injury. Make small cuts to avoid removing too much material or making too large or deep a cut.

DEBURRING: Cutting may leave rough edges ("burrs") on some parts. Remove the burrs by sanding the rough edge or trimming the burr with a small knife. Leaving burrs on parts, especially crimps, may cause the nitinol actuators to break.

SANDING: The ends of aluminum tubing should be sanded with fine (320/360 grit) sandpaper to debur them. Lightly sand nitinol and music wire with ultra fine (600 grit) sandpaper paper to remove oxide. Sand the wire after it is bent or knotted to avoid breaking it; sanding wire too much may weaken it enough to break during assembly or when the robot is operating.

KNOTTING AND CRIMPING NITINOL WIRE: Nitinol is similar to stainless steel. The .004" nitinol used in this robot can be knotted without breaking the wire as long as the knot is not tightened excessively. Knotting and crimping nitinol wire is the most reliable way tested to attach the actuators. Nitinol actuators must be taut, and attached so they cannot pull loose, if this robot is to walk well. The knot-and-crimp attachments have proven reliable for over 300,000 cycles (approximately 100 hours of continuous walking).

Of the other ways to anchor nitinol actuators, a U-shaped bend in the nitinol wire can pull far enough out of a crimp to reduce leg motion; soldering is difficult to control because the wire contracts and may lose its "memory"; and soldering and epoxying nitinol wire may not hold under repeated actuation. Pinning or screwing the nitinol wire to the leg is more complex than knotting and crimping (but screws are easy to use on the body).

To tie a knot, make a loop in the wire, run one end of the wire through the loop to make an overhand knot, then pull by hand to decrease the diameter of the knot's loop to about 3 millimeters. Slide the knot nearly to the end of the wire using a length of stiff wire, then grasp the end of the wire nearest the knot with the needle-nose pliers, and holding the other end of the wire (or the crimp if one is attached to the other end) with your hand, pull sharply several times with the needle-nose pliers to tighten the knot. The knot is tight enough when a small loop, approximately 0.1 millimeters in diameter, remains. Continuing to tighten the knot may break the wire.

Insert Figure 2 here. Drawing

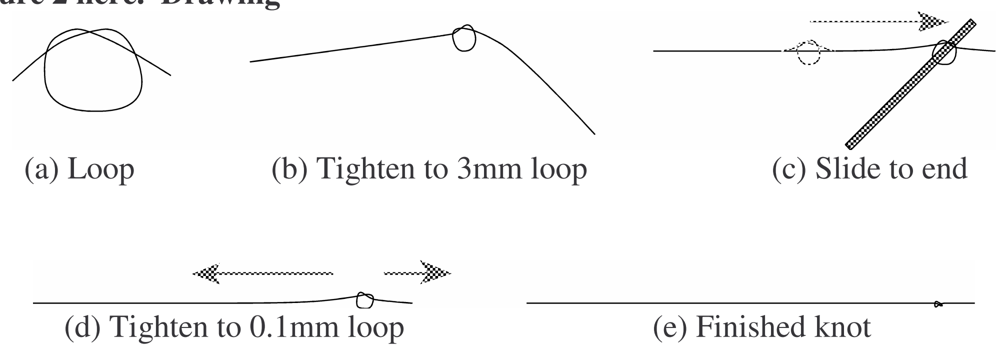
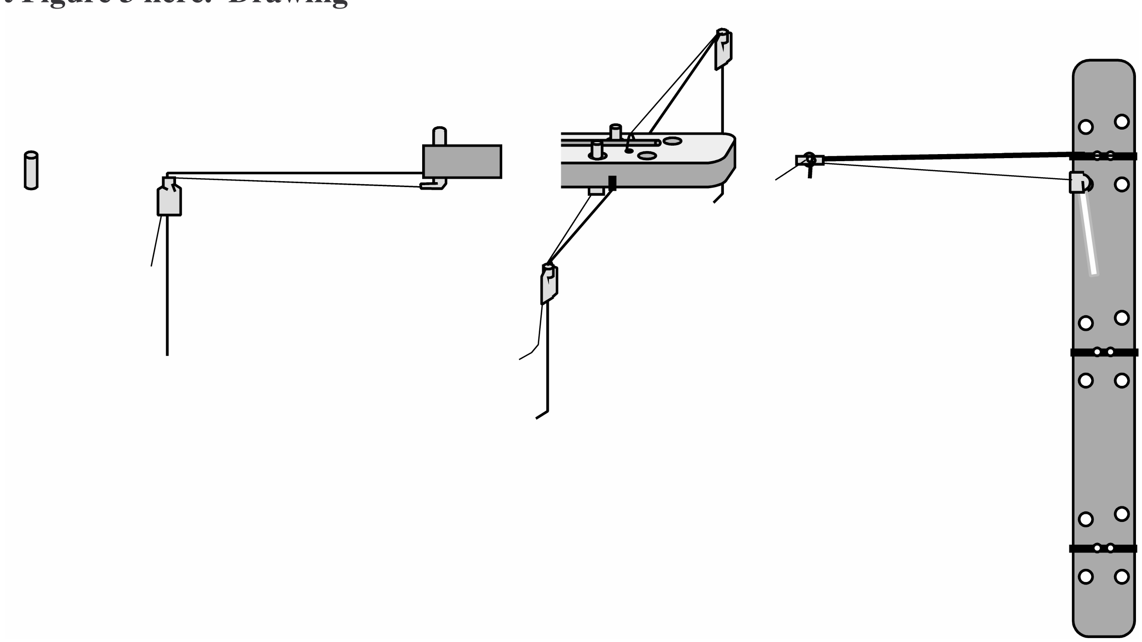


Figure 2: Knotting nitinol

Crimps are hollow connectors that are squeezed shut to hold, attach, or connect one or more objects. This robot uses short lengths of aluminum tubing as crimps to anchor the knotted nitinol actuator wires securely. Leg crimps hold both the actuator wire and the music-wire leg. Leg crimps directly attach and electrically connect the actuator wire to the music-wire leg. We use screws to attach the nitinol to the body.

Insert Figure 3 here. Drawing



(a) Crimp (b) Side view (c) Side view rotated 90° (d) Bottom end view

Figure 3: Leg crimp (views with repect to leg crimp)

FIXING MISTAKES: No matter how carefully you work, mistakes do happen. Most are easy to fix, because almost all steps in the construction of Stiquito allow some tolerance, except for tensioning the nitinol actuator wires, where no slack is allowable. Here are some common problems, and how to work around them:

- *Music wire bent incorrectly.* 90 degrees bends or greater can be re-bent gently once or twice before breaking the wire. Bends less than 90 degrees , such as the 15 degrees V-clamp in the legs, usually break if rebent.
- *Knot in wrong place.* Tie a new knot and keep going. You may want to cut the nitinol to 70 millimeters lengths instead of 60 millimeters lengths for this reason. Untying tight knots in nitinol usually breaks it.
- *Crimp must be removed or replaced.* Crimps can be gently squeezed across the wide dimension to undo them, but should then be discarded. Extra tubing is provided to make new crimps.

Required Soldering Skills

Soldering mechanically and electrically connects components and integrated circuits to the interface card. The basic technique for soldering is described below [11]. You may want to practice on an old circuit board before you solder the parts to the interface card.

✓ Use the soldering iron's tip to heat the **pad**, not the integrated circuit pin. When the pad is hot, touch the solder to the heated pad, and the solder will flow onto the pad and the pin.

✓ Use just enough solder to wet the pin and cover the pad.

✓ Each solder joint should be bright, shiny, and have flowed evenly around the pin on the pad. The solder on adjacent pads must not touch.

× A solder joint should **not** be dull, cracked, or beaded up on the pad.

× A solder joint must **not** cross between two pads, or a pad and a trace. This will create a short circuit. Your interface card will almost certainly **not work correctly**.

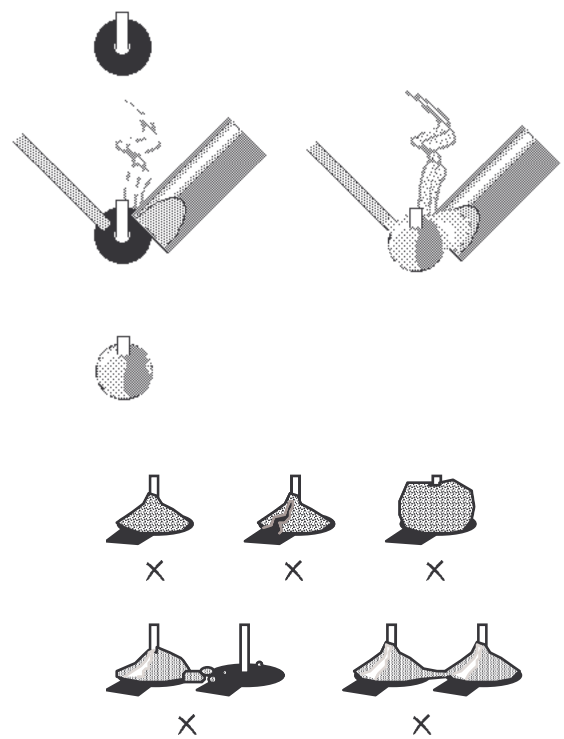


Figure 4: Soldering skills

After you have finished soldering, you should examine the board for workmanship errors. Check the board for short circuits and broken traces:

✓ Examine the wiring side of the interface board. Look at places where one trace (wires on board) or pad (round circle on board) is near another; check that they do not touch. Look at long traces and near bends; check that the trace is not broken at that point.

✓ If traces or pads touch when they should not, use the knife to cut the unwanted connection.

✍ If a trace is broken, lightly sand it on either side of the trace, then solder the broken ends together using a piece of fine wire to bridge the gap.

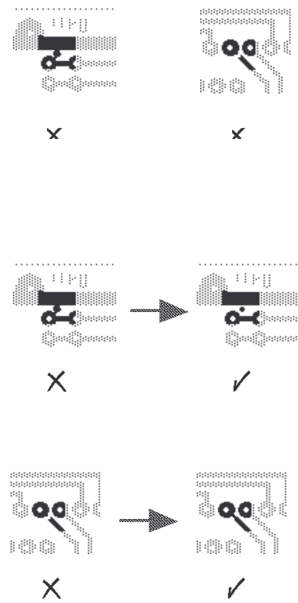


Figure 5: Examining the board for soldering faults.

PRECAUTIONS

✓ Soldering irons get **very hot**.

✗ Do **not** touch exposed metal on a hot soldering iron. Hold it by the insulated handle.

✗ Do **not** lay a hot soldering iron on the work surface or flammable material.

✓ Use a soldering iron holder or lay a piece of wood under-but-not-touching the tip to protect your work surface.

✗ Do **not** handle the integrated circuits by the pins.

✓ In winter and dry weather, touch a large metal object (table, door frame) to discharge any static electricity before handling integrated circuits.

✓ ALWAYS wear safety glasses when performing this work.

Constructing Stiquito

Stiquito has four major assemblies: the controller Printed Circuit Board (PCB), the body, the legs and power bus, and the actuators. The actuators are made of nitinol wire.

Insert Figure 6 here. Drawing

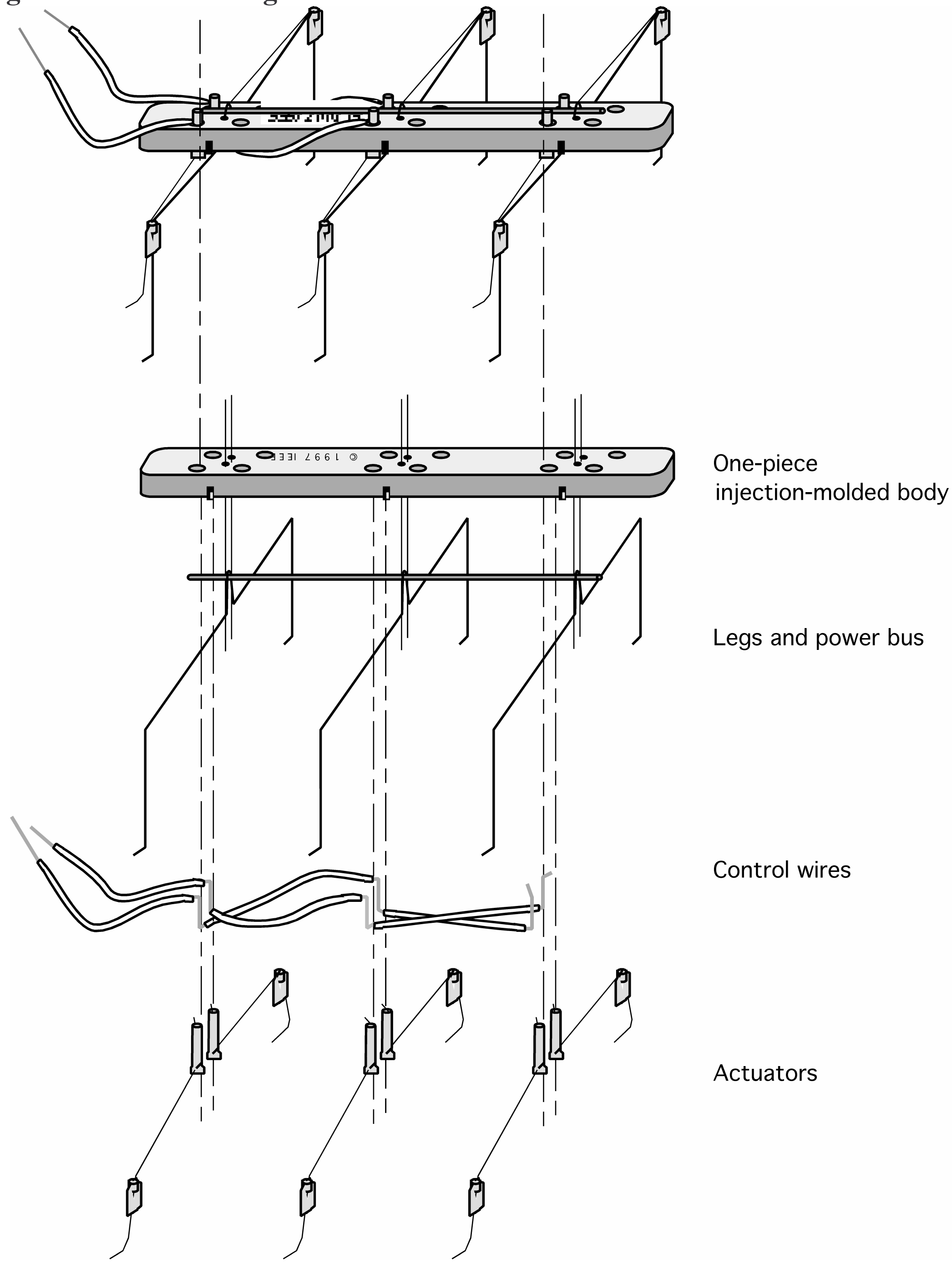


Figure 6: Stiquito assemblies

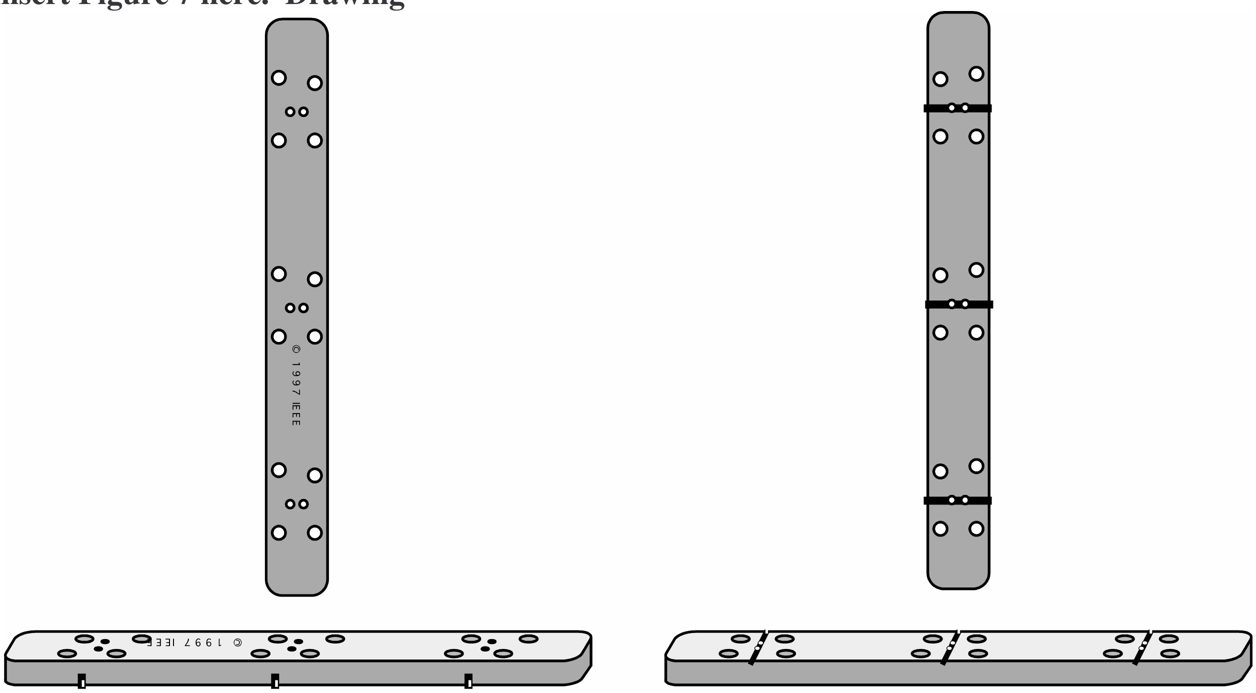
The Body

The body provides structural strength and locates the attachment points for the legs and the nitinol actuator wires. The body is molded with holes and grooves. Examine the plastic to ensure that every hole goes all the way through and that there are no rough edges.

The plastic body has 18 holes. The smallest set of holes is used to attach the legs to the body. The set of six large holes that have three holes slightly offset will be used to assemble the leg actuators. The following instructions use only these twelve holes.

The other set of six holes that are parallel to the small holes can be used for other purposes, including assembling Stiquito with legs that have two degrees of freedom (see Chapter 6 and 7).

Insert Figure 7 here. Drawing



(a) Top side (b) Bottom side

Figure 7. The molded body

The Legs and Power Bus

The legs are assembled in pairs from three 100 millimeters lengths of .020" music wire. The music wire legs perform three functions:

1. *Support*. The legs support the weight of Stiquito, and its battery and control electronics. Because the wire is bent to fit into a leg clip groove molded in the body, each leg in the pair is mechanically isolated.
2. *Power distribution*. All legs share a common electrical power connection to the power bus, and route current to the nitinol actuator wires. The V-bend in the music wire clamps the power bus to the top of the body and electrically connects it to the legs.
3. *Recovery force*. The music wire acts as a leaf spring to provide recovery force for the nitinol wire actuator. Without this spring, or if the actuator is attached loosely, the nitinol wire will contract, but fail to return to its original extended length.

Insert Figure 8 here. Drawing

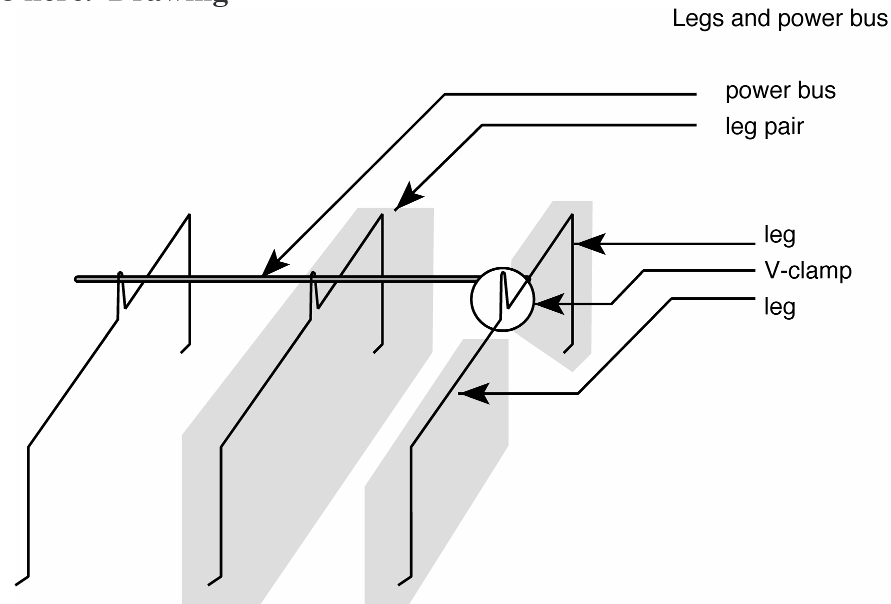


Figure 8: Legs and power bus

Insert Figure 9 here. Drawing

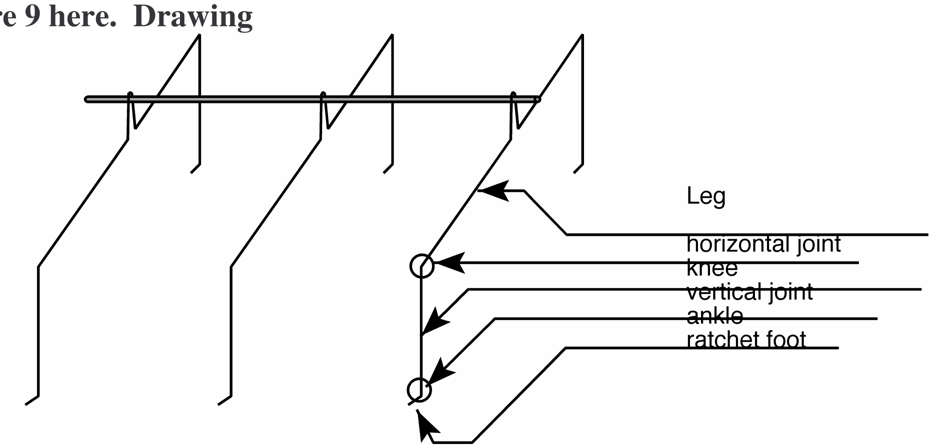


Figure 9:   Leg detail

Begin assembling the legs by using three 100-millimeter lengths of .020" music wire. Bend each music wire in the middle to a 15 degrees angle. Do not bend the wires too far, or they may crack or break. The apex that forms the V-clamp should be rounded, not sharp. Lightly sand the inside of each V-clamp with the 600 grit sandpaper to remove oxide.