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IBM Research Report

PONG: The Attentive Robot
How to Build a Pong Robot

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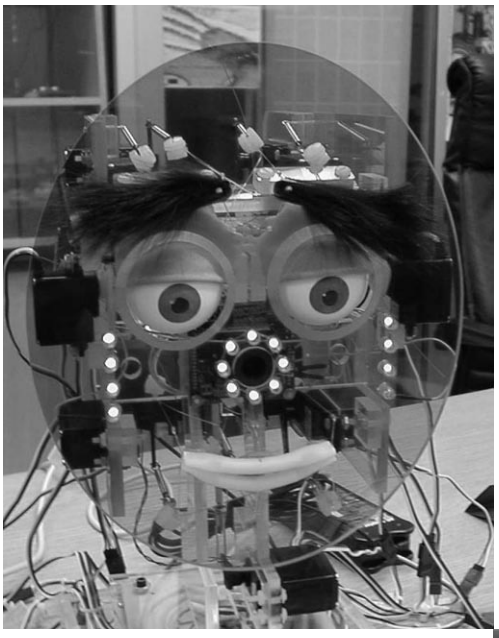
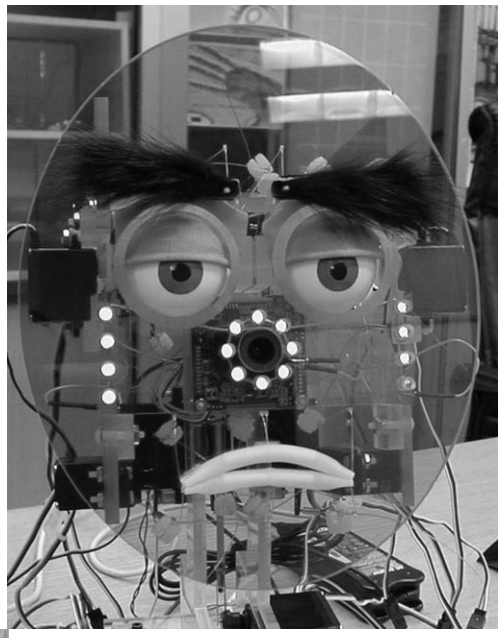
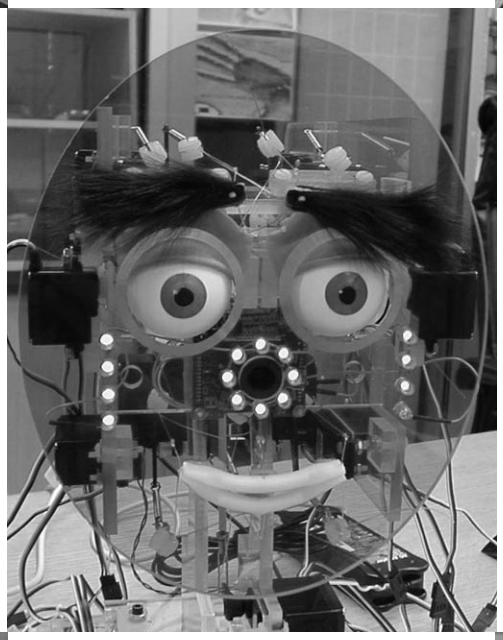


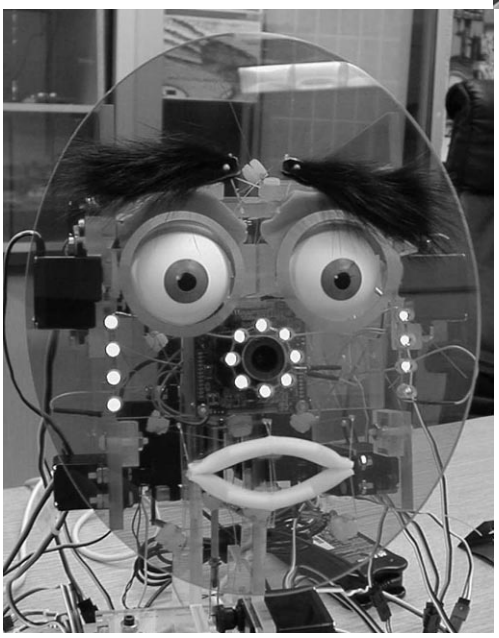
PONG

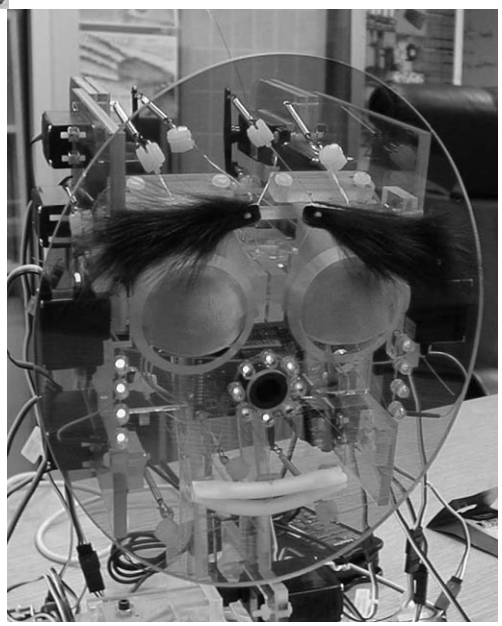
the attentive robot





How To Build a
PONG robot



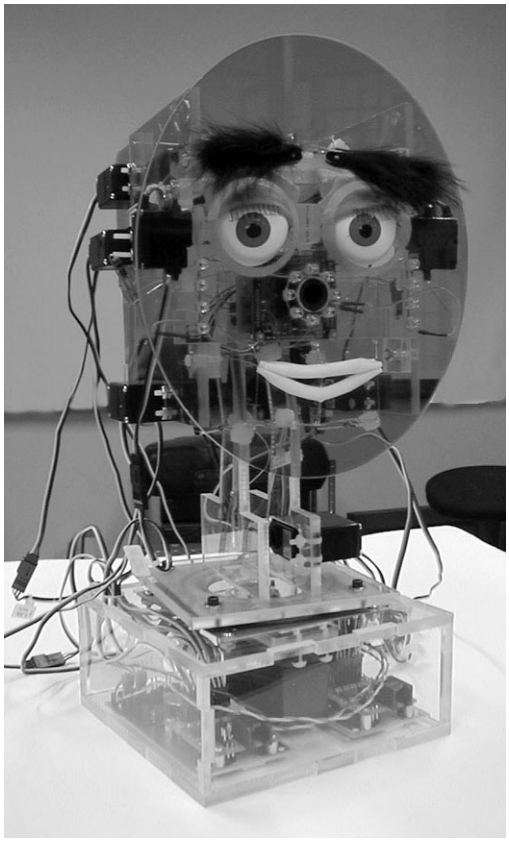


April 12, 2001
IBM Almaden Research Center
Dave Koons

PONG
The Attentive Robot

PONG was designed and built to demonstrate a set of ideas and technologies that were developed as part of the Blue Eyes Group at IBM's Almaden Research Center in San Jose. Blue Eyes began as an Adventurous Research project into the use of sensing technologies, such as video, at the human-computer interface. The group consists of researchers in computer vision and human-computer interface.

PONG is not a product, a toy, or an "industrial strength" robot. He is built of simple components and was intended simply as an entertaining demonstration of an "attentive robot." A person can approach PONG, make eye contact, and see PONG's reaction: PONG looks back and smiles. This simple but powerful exchange serves to establish an open channel and an understanding that both parties are ready and willing to begin a dialog. The name "PONG" is derived from the use of ping pong balls as eyes and from this "bouncing back" of eye contact.



PONG demonstrates two results of this research. First, PONG demonstrates a robust method of tracking people's pupils in video images through the use of a simple structured illumination scheme. PONG inludes two circuits of IR LED illuminators. One circuit is a tightly arranged circle of LEDs surrounding the camera's lens and produces a "bright pupil" (red eye). The second circuit is composed of two bars placed away from the lens and produces a normal-looking "dark pupil." By taking two sequntial images, one with bright pupils and the second with dark pupils, a simple differencing operation will produce an image that highlights the position of people's pupils. Second, PONG demonstrates that once the pupils/face are detected, further processing of key areas of the image of the face can detect simple facial expressions (happy, sad, angry, surprise).

The PongVideo software includes three basic modes of tracking. First, in the "detection mode," PONG will direct his eyes to "look at" each detected face in the image from the PONG-mounted camera. Second, in the "motion-tracking mode," PONG will detect major areas of motion in the video image and direct PONG's eyes and head to position the area of movement in the center of its field of vision. Finally, in the "face expression tracking mode," PONG will track a single face and attempt to dynamically mimic the shape of the person's eyebrows and mouth.

PONG is built from laser-cut acrylic plastic parts and inexpensive hobby RC components. PONG's features are made of ping pong balls, fur strips from a fly fishing shop, and latex tubing. This manual is intended to allow anyone with a basic set of shop tools to construct their own PONG robot. Included with this document are all the digital files for the drawings and templates required for fabricating the parts and sub-assemblies of a PONG robot.

NOTE: all references to "left" and "right" in this manual refer to PONG's left and right.

Table of Contents

I. PARTS AND TOOLS

Each PONG robot requires a wide range of parts from many different sources/suppliers. Refer to Appendix X for a complete parts and supplier list.

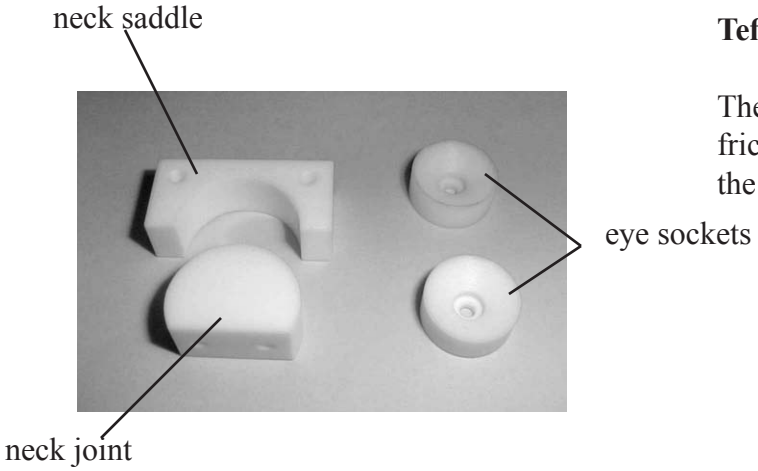
Servos

PONG uses 5 different RC servos from Tower Hobbies (www.towerhobbies.com):

- 1 TS-75 ¼ scale servo (neck azimuth/pan)
- 1 TS-71 super torque servo (neck elevation/tilt)
- 4 TS-69 standard ball-bearing servos (eyes)
- 6 TS-53 standard servos (eyebrows and mouth)
- 2 TS-15 micro servos (eyelids)

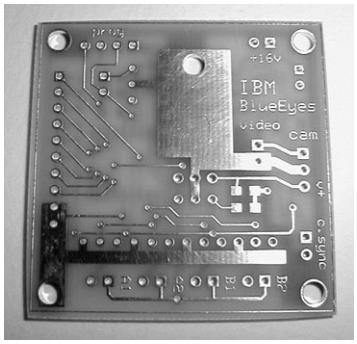
Other parts and supplies (not shown)

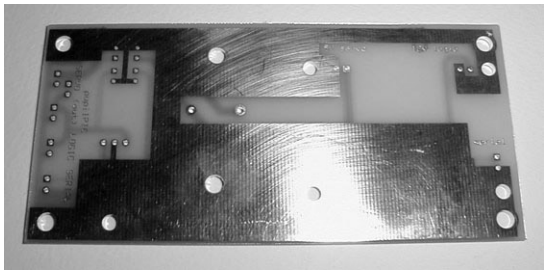
Ping pong balls (2) - eyes
Tubing (latex, about 6") - lips
Rubber insulated wire (white, about 6") - lip stiffener
Rabbit fur strips (two 1 ½" strips) - eye brows
Nylon hosiery - eye lids
Fishing line (0.015" dia.)
Small white glass beads
Felt (black and orange)
22 gauge steel wire
18 gauge steel wire
rubber cement
Plastic welder
Acrylic solvent/cement
1/32" I.D. Tygon tubing
#2 tackle snap connectors



Teflon parts

These parts are machined from teflon to provide low-friction joints for the neck and eye sockets. Refer to the dimensional drawings in Appendix X for details.





Printed circuit boards

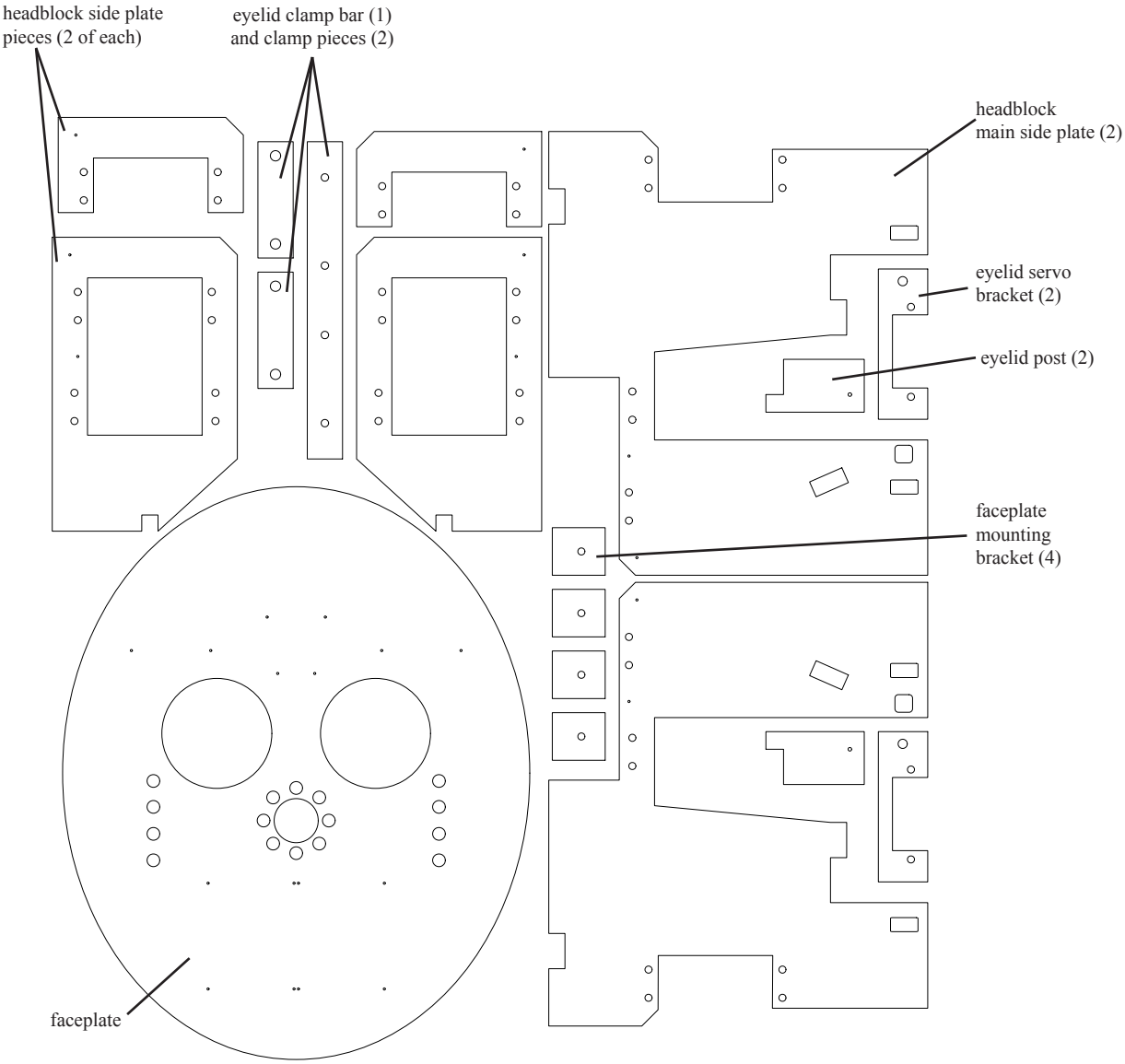
These boards were manufactured by expressPCB (www.expresspcb.com) using their proprietary drawing application. Refer to the files "PupilSX.pcb" and "PowerJ.pcb".

Tools

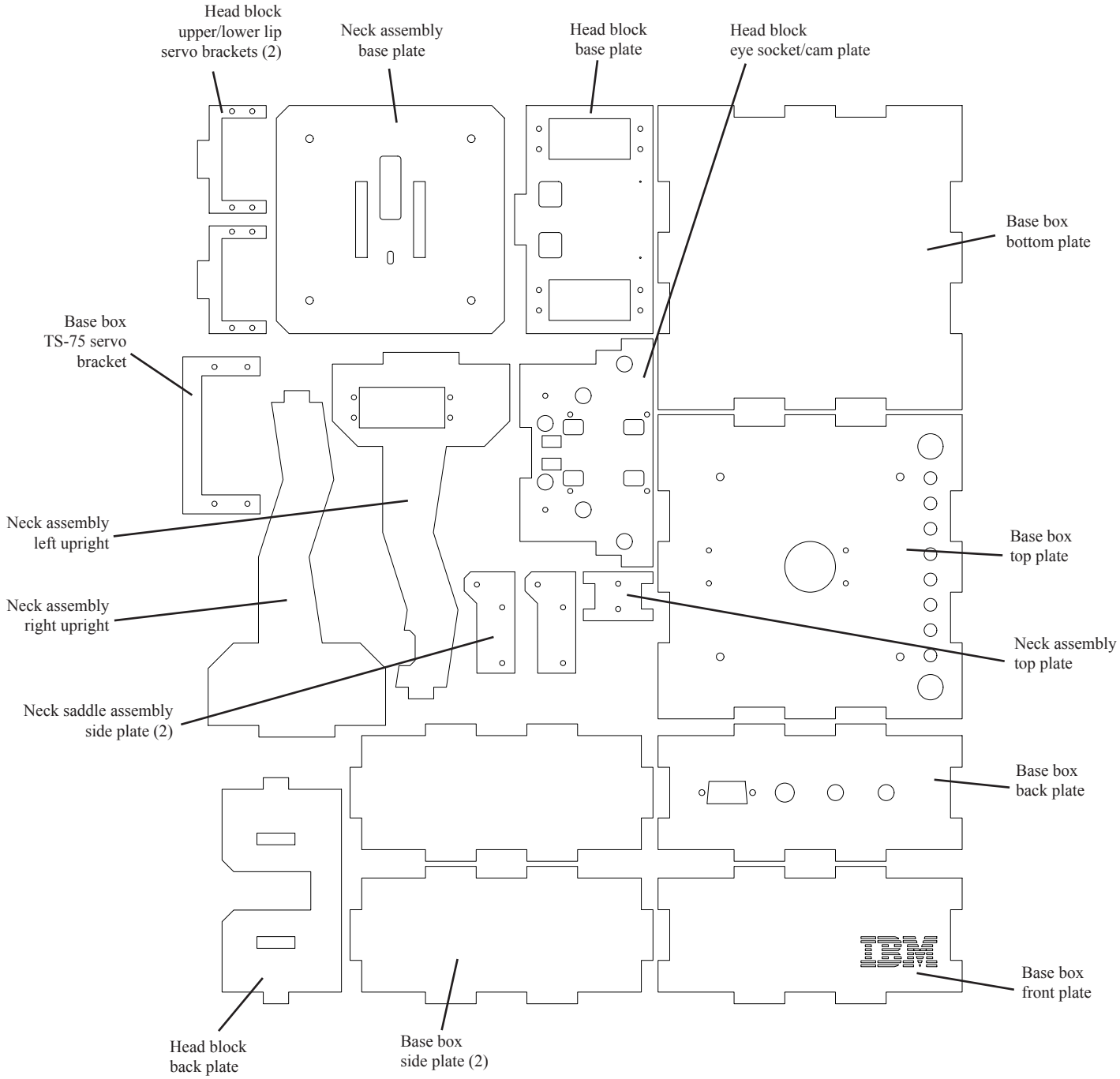
Very fine round file
Carbide router with 45-degree bit
and 1-1/2" circle template
Scissors
Needle nose pliers
Diagonal wire cutter
6" Forceps
Screwdrivers - small Philips and flat
Drill and bits (#35, #36, 0.25")
Countersink bits (1/2", 5/16")
Tap set (6-32 tap)
Solder iron and supplies (solder, wick)
Dremel tool
Sewing needle
Paper clip/hook
Wire-bending pliers (nice but not necessary)

Acrylic parts

The basic structure of PONG is constructed from 1/4” thick acrylic plastic sheets cut into the following parts. The drawing on this page and on the next page show the pattern of cuts to control a laser-cutting CNC machine. The parts shown on this page are to be cut from an amber-colored sheet of acrylic plastic. See the files “amber.dxf” or “amber.mcd” (vectorworks native file format).



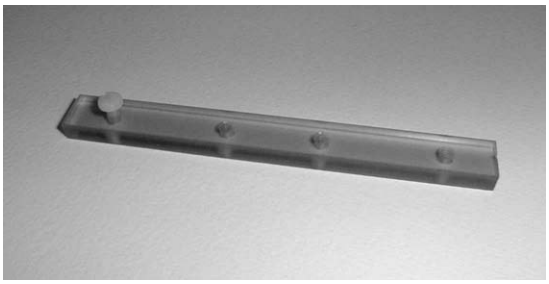
Smoke-colored acrylic parts (0.25” thickness)
See the files “smoke.dxf” or “smoke.mcd”.



II. ACRYLIC ASSEMBLY

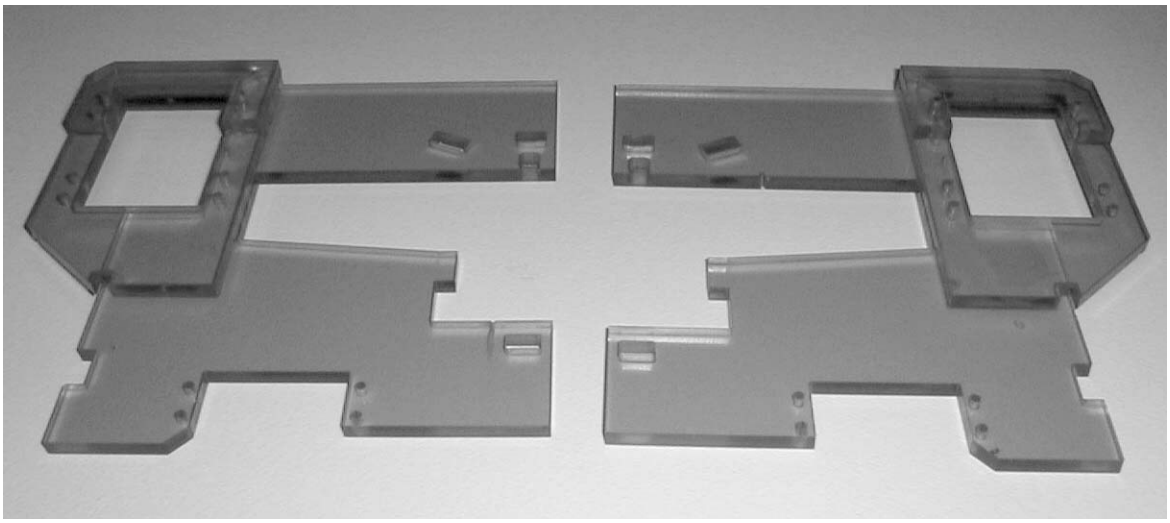
Head block

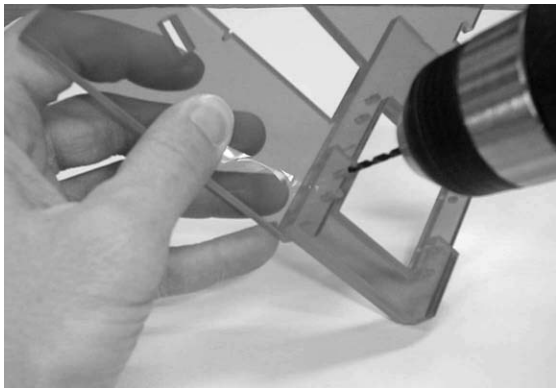
Use an acrylic cement/solvent such as xx for all acrylic-to-acrylic joins.



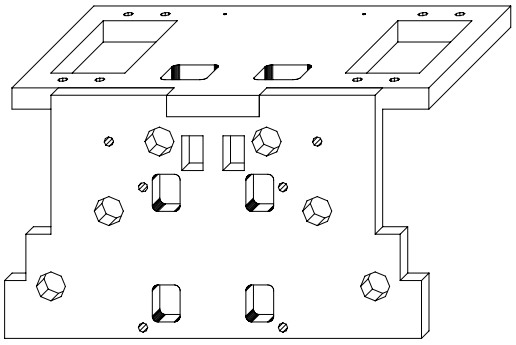
Tap the four holes in the eyelid clamp bar for 6-32 threading.

Assemble the left and right side plates of the head block. Use the servo openings and mounting holes to align the three plates for each complete side plate.

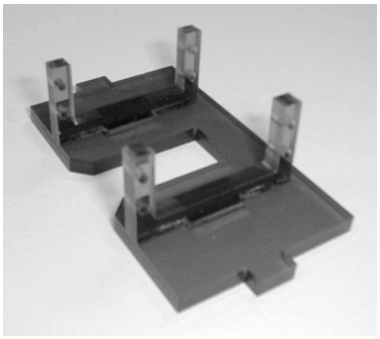




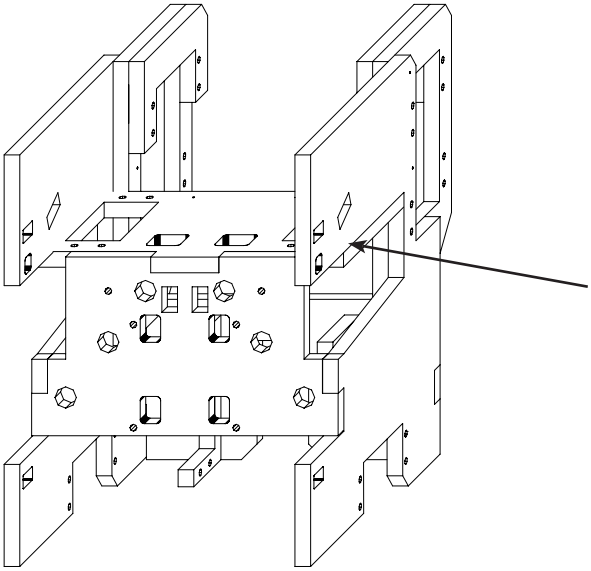
After the side plates are dry, drill out all the servo mounting holes in the head block parts with a #35 drill bit (0.1100”). This is especially important for the holes that pass through the multiple layers of the side plates.



Using a square to obtain a 90 degree angle, glue the (head block) base plate to the eye socket/camera plate.

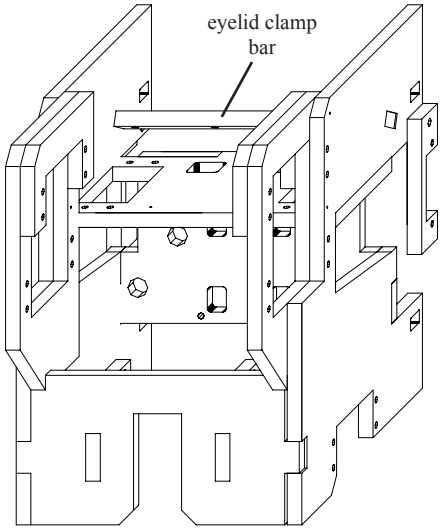


Glue the two servo brackets for the upper and lower lip servos to the back plate.

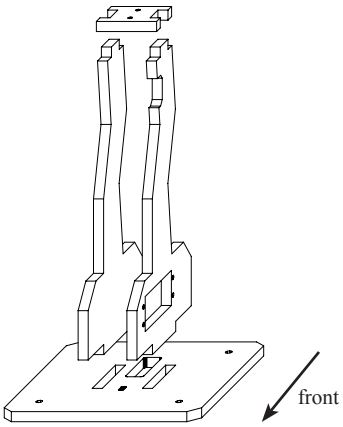


Combine the parts from the previous steps into the head block “box” configuration.

Slide the eyelid clamp bar into the slots in the side plates and glue in place.



Neck

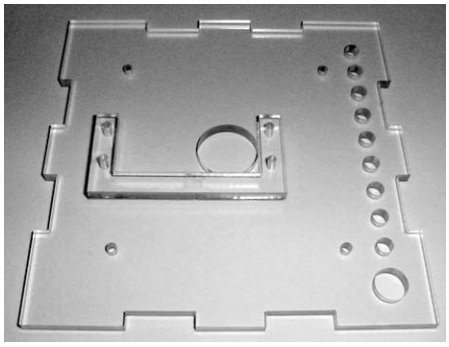


Using a square, glue one of the neck uprights onto the neck base plate. Use this diagram to get the front/back and left/right orientation of the upright correct.

Repeat for the second upright.

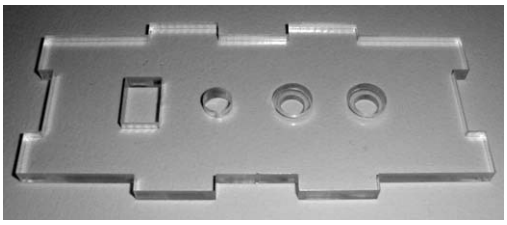
Glue the top plate to the top of the two uprights.

Base box



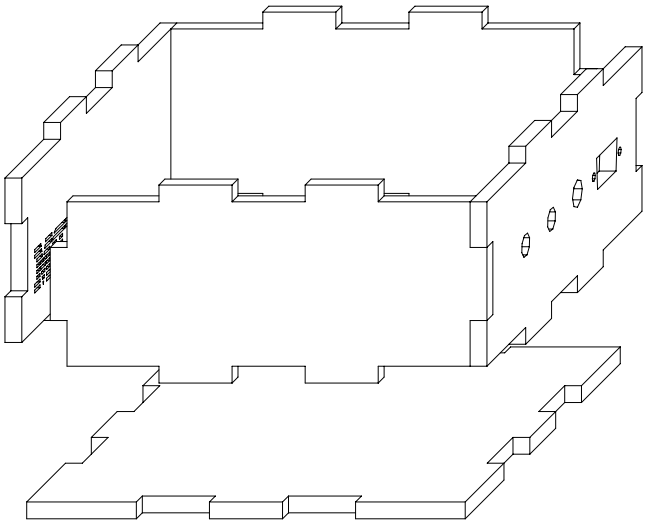
Glue the TS-75 mounting bracket onto the bottom of the base box top plate. Use the four mounting holes to align the bracket.

Drill out the four mounting holes with a #36 (0.1065”) drill bit to clean up any misalignment. Finally, tap the holes for 6-32 threading.



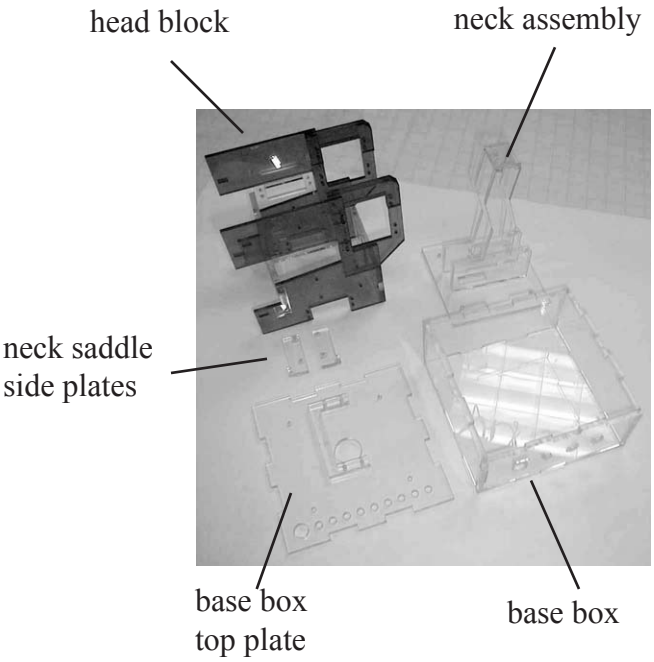
Countersink the power jack holes in the back plate of base box with a ½” countersink bit.

Using a square, glue one of the side plates to the front plate.



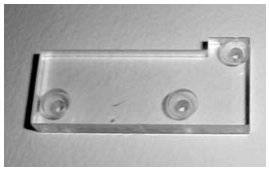
Repeat with the other side plate and the back plate.

Combine the two pieces from the previous steps with the base plate to complete the base box. Note that the top plate is not glued but fits tightly into its slots and allows access to the cabling and electronics inside the base box.

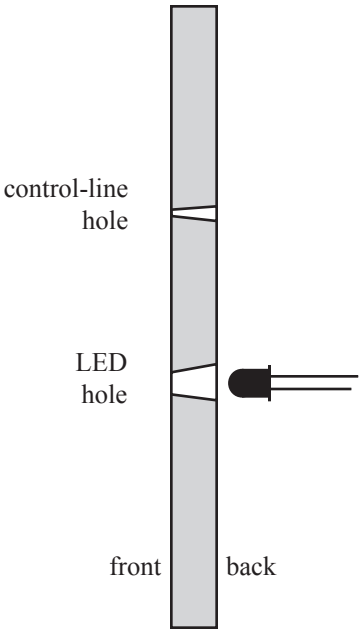


Assembled acrylic parts

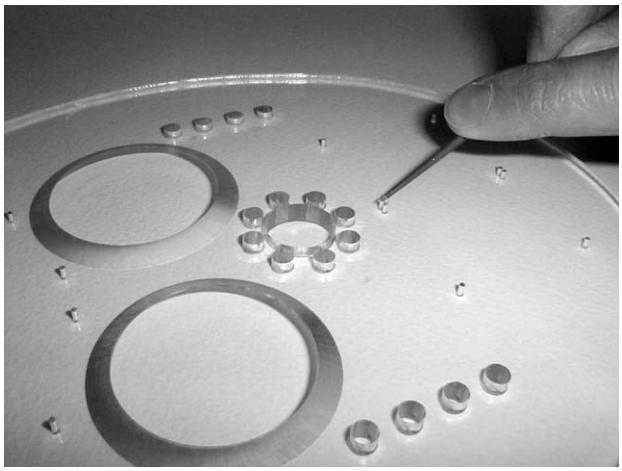
Other acrylic preparations



Countersink holes in one of the acrylic side plates of the neck saddle assembly with a 5/16” countersink drill bit.



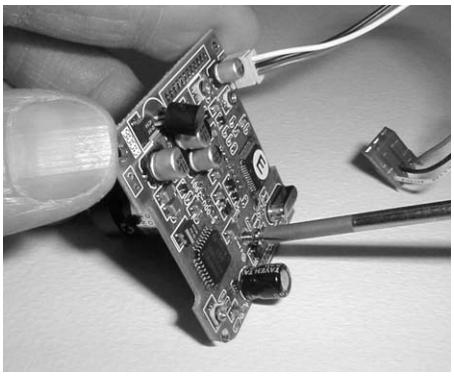
Laser cutting produces a slightly beveled cut edge due to the refraction of the laser beam as it hits the front surface of the acrylic sheet. Look at the edges and holes in the faceplate and determine which surface was the “top” surface (holes in the top surface will be slightly smaller than their exit diameter in the “bottom” surface) Select the top surface as the forward-facing or front surface for PONG’s faceplate. The LEDs can now be inserted from the back surface and will naturally wedge into the hole as it becomes smaller towards the front surface.



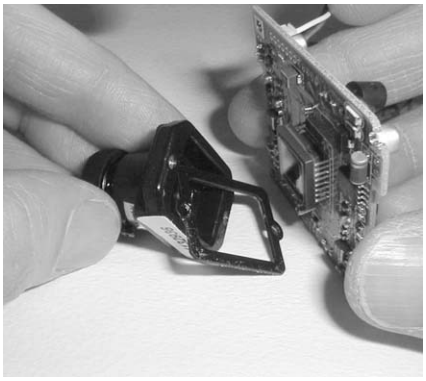
Working from the front surface of the face plate, round off the control line holes for the eye brows and mouth with a fine round file. Try to achieve a smooth “rain gutter” profile to the hole to ease the stress on the nylon control line as it makes its 90-degree turn through the face plate.

Router eye holes with a 45 degree bit from the back of the face plate.

III. CAMERA PREPARATION



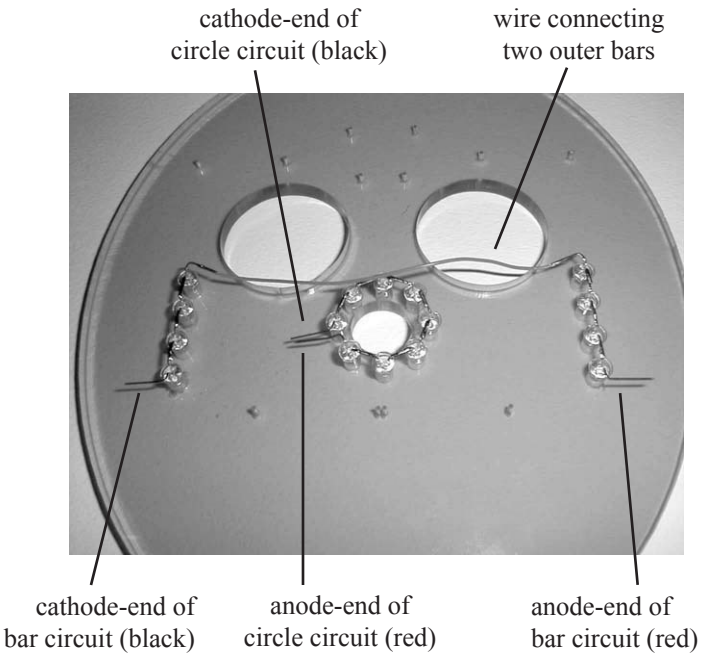
Remove the two small screws holding the lens housing onto the PCB of the camera.

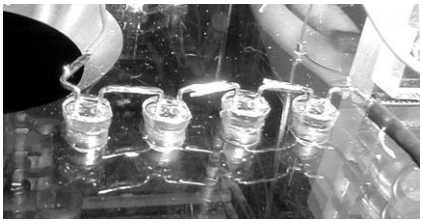


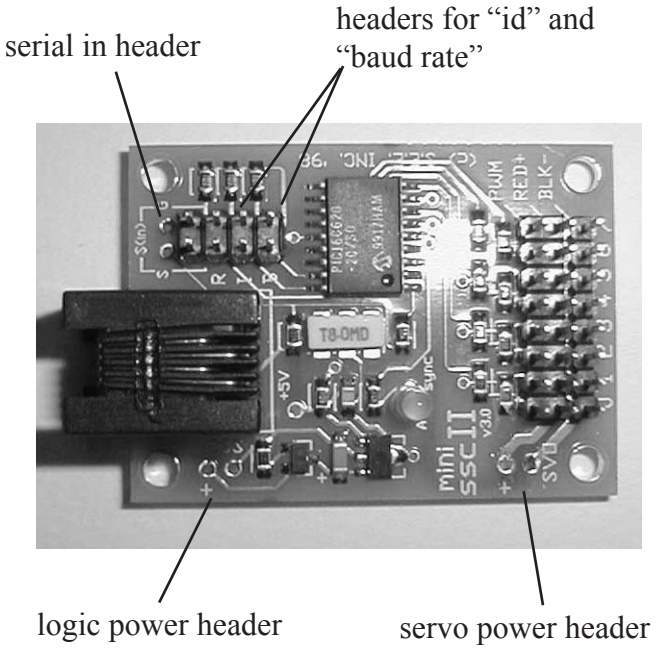
Remove the lens housing. Be careful not to scratch or damage the exposed CCD on the front of the camera PCB.

Cut a small rectangle of Wratten No.87 filter to fit inside the lens housing.

Carefully insert the Wratten filter inside the lens housing and reinstall the housing on the camera PCB with the two small screws.







IV. ELECTRONICS

LED circuits

Insert the 16 IR-LEDs into the faceplate from the back surface. Align the LEDs to create two (inner ring and outer bars) circuits of 8 LEDs in series (anode of one LED adjacent to the cathode of next LED).

Carefully bend the leads on each LED over to meet its neighbor LED and cut off the excess. Carefully solder leads together. For the inner “ring”circuit, leave two leads long to allow attachment of the inner LED cable. For the outer “bars” circuit, use a short length of 28 gauge insulated wire to bridge between the two sets of 4 LEDs. Leave the bottom two leads of each of the side “bars” long to allow connection to the outside LED cable.

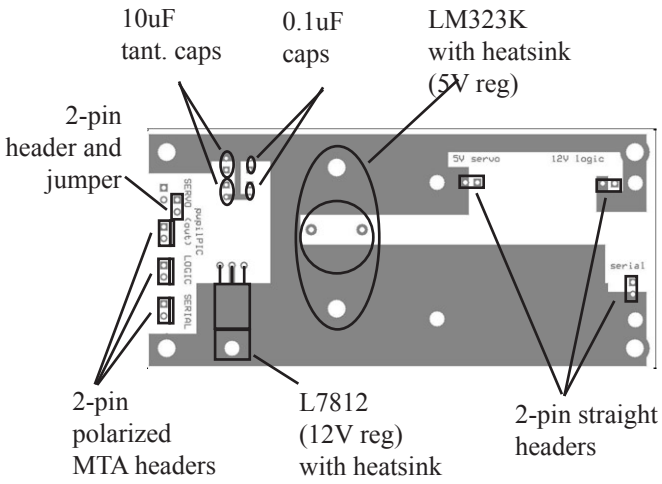
Label the end of each LED circuit by putting a colored dot on the back of each terminal LED (red = anode, black = cathode). This will ease identifying the polarity of the LEDs when connecting the LED cables.

SSCII modifications

The Scott Edwards SSCII servo controller board must be modified to allow it to be mounted as a daughter board to the complete Power Junction board. Desolder and remove the 2-pin headers for 1) servo power, 2) logic power, and 3) serial in (this pin needs to be cut from the larger block of header pins).

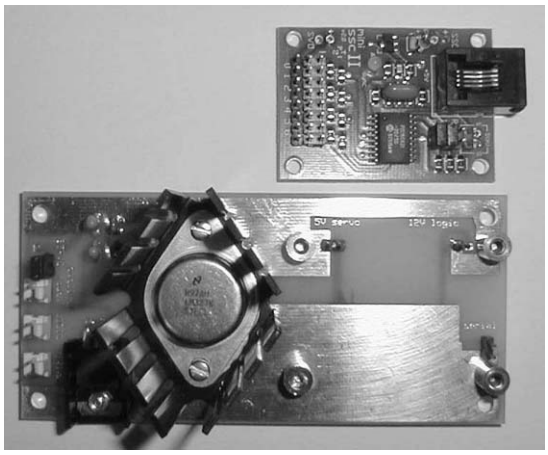
Add a jumper to both SSCII boards on the “baud rate” header (labeled “B” on the PCB) to set the communication baud rate to 9600 bpm. Add a jumper to one of the SSCIIs on the “id” header (labeled “I”) to set this board to servos 8-15 (this will be the controller for the right side of Pong). Refer to the Scott Edwards data sheet for the SSCII.

PowerJunction board

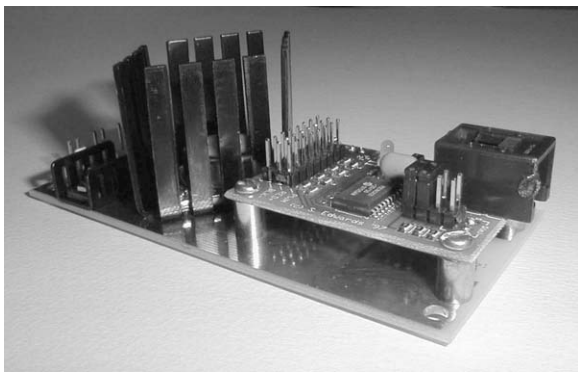


Populate the two PowerJunction PCBs. Each board contains these components:

three 2-pin MTA polarized headers
four 2-pin straight headers
two 10uF tant. caps
(be careful to get polarity correct)
two 0.1uF caps
one L7812 TO-220 +12V regulator
one LM323K TO-3 +5V (3 amp) regulator
four 5/16” 4-40 spacers



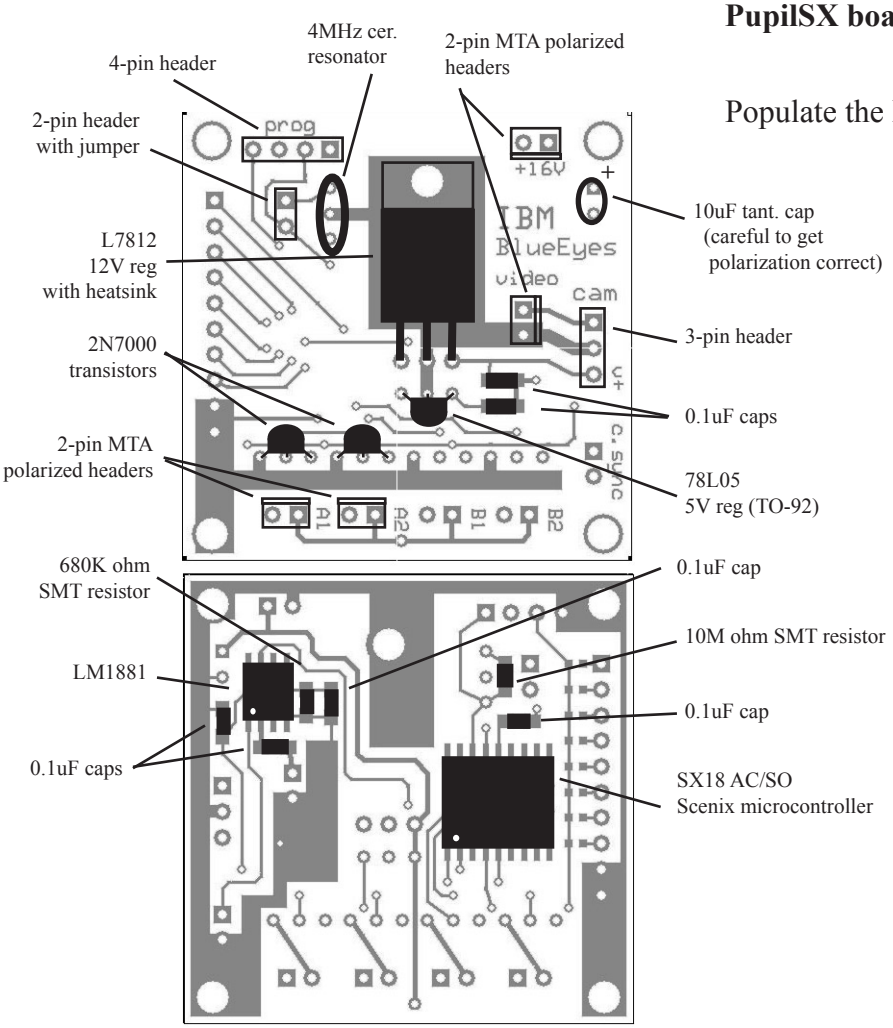
Mount the four spacers on the PowerJunction PCB. Carefully align the modified SSCII board with the three 2-pin headers and four spacers on the Power-Junction board. Mount the SSCII onto the spacers with four 4-40 screws. Solder the three 2-pin headers passing up from the PowerJunction board to the SSCII. Once these connections are soldered and the spacers tightened the two boards form a rigid platform for most of the electronic connections in PONG.

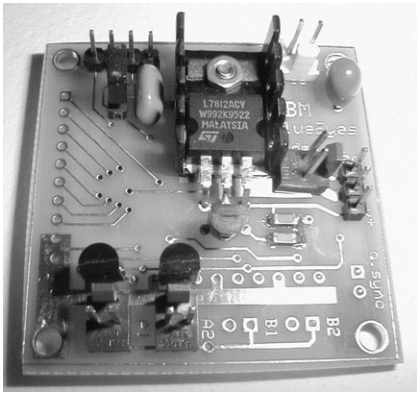


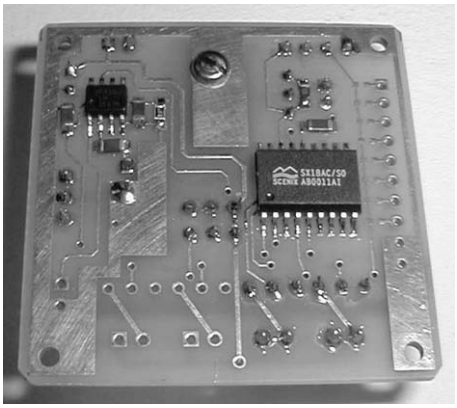
A complete PowerJunction/SSCII board.

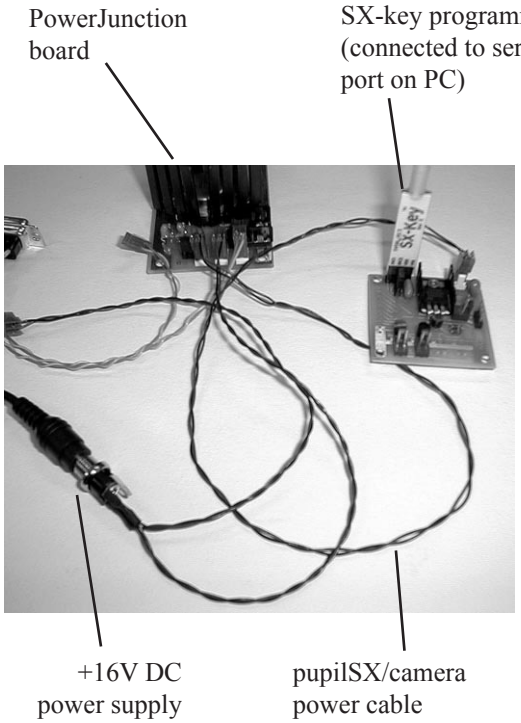
PupilSX board

Populate the PupilSX board with these components.



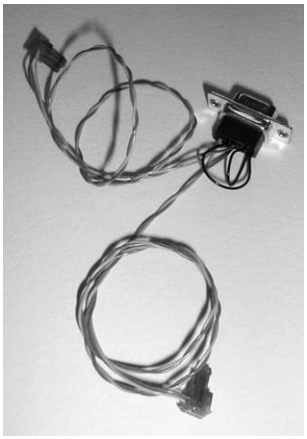


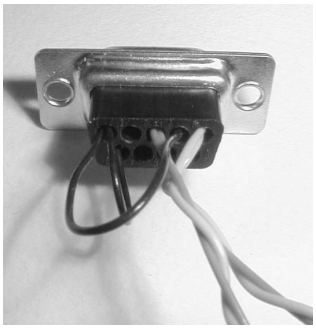




Program the Scenix microcontroller

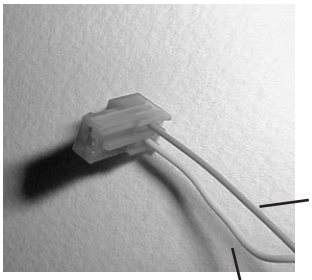
Attach the SX Key to the 4-pin “programming” header on the pupilSX board. Remove the jumper that is adjacent to the header and save it in a safe place. Connect the camera/pupilSX power cable between a PowerJunction board and the pupilSX board. Connect the PowerJunction power cable and plug in a 16V power supply (ThinkPad power module). Using the SXkey assembler application assemble and download the “pupilSX.asm” code to the SX microcontroller.

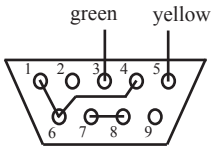




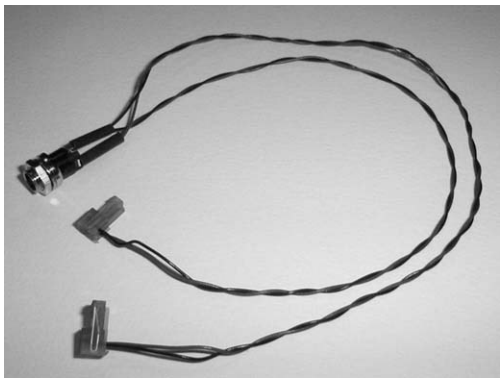
Cables

Serial cable: DB-9 female, split to two 6” 2-wire cables (green = data, yellow = ground) terminated with 2-pin MTA connectors.

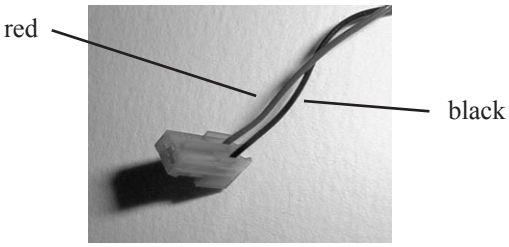


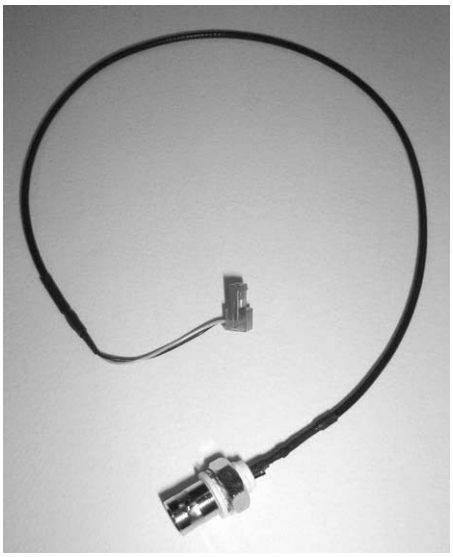


solder side of DB-9 female connector

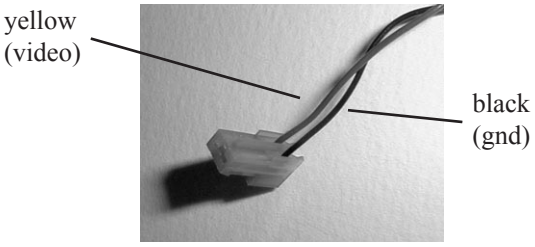


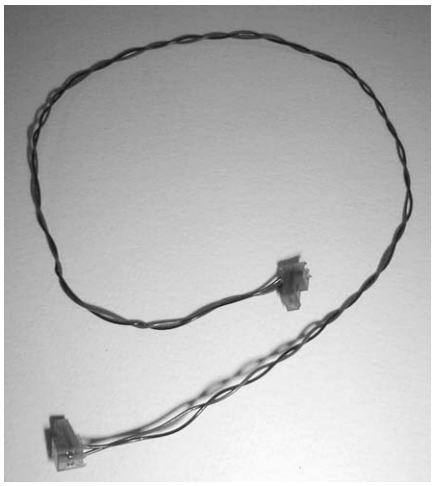
Power cable: 5.5mm(2.5mm inside) power jack, split to two 8” 2-wire cables (red = +16VDC, black = ground) terminated with 2-pin MTA connectors.



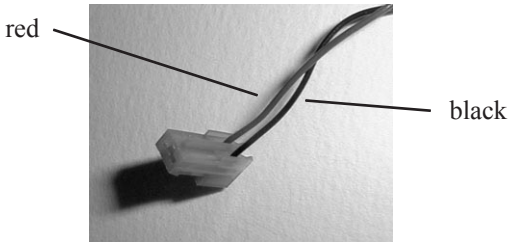


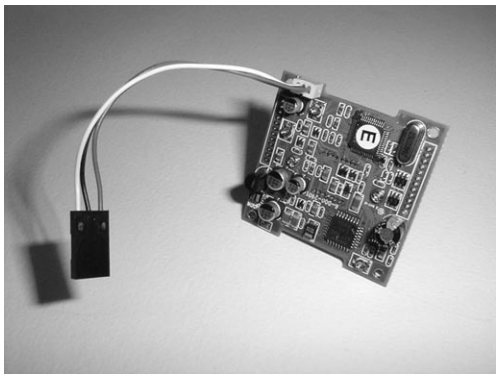
Video cable: BNC female bulkhead, 15” shielded coax cable (center = video, shield = ground) terminated with a single 2-pin MTA connector.



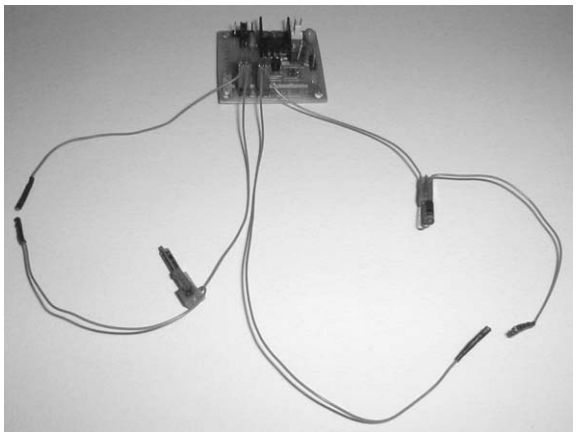


PupilSX/Camera power cable: 15” 2-wire cable (red = +16VDC, black = ground) terminated on both ends with 2-pin MTA connectors.



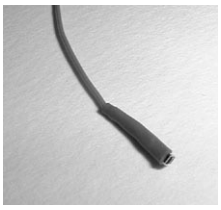


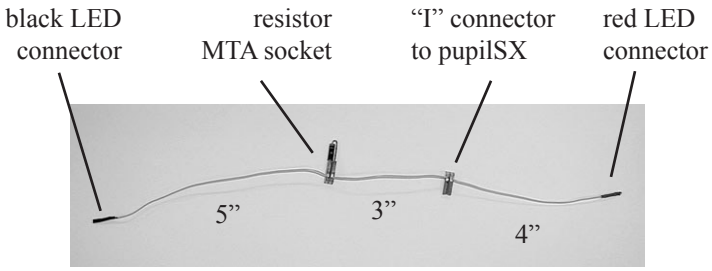
Camera/PupilSX cable: a micro-connector with 3 wires is incuded with the Mintron board camera. Cut the wires to about 3” and add a non-polarized connector housing (0.100”) on the other end of the loose wires. Maintain the same order of colors as the connector to the camera: red (+12VDC), black (center, GND), and white (video).



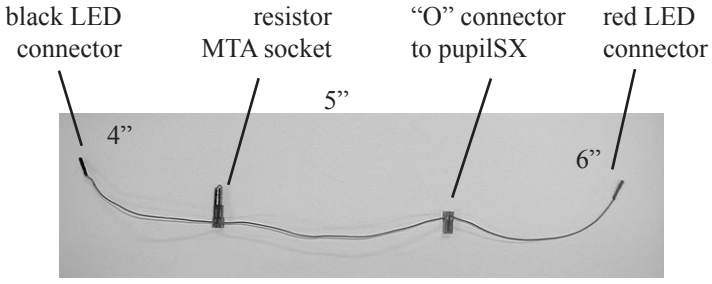
Inner and Outer LED cables:

The inner and outer LED cables connect between the pupilSX board and the leads on the LED circuits imbedded in the faceplate. They include an MTA connector near the midpoint of the ground wire for inserting a series 2-watt resistor. This allows easy adjustment of the current/brightness of the LED circuits. The ends that connect to the LED leads are female crimp-style pin connectors with heat shrink insulation. Colored heat shrink can be used to color-code the LED connectors (red, black).

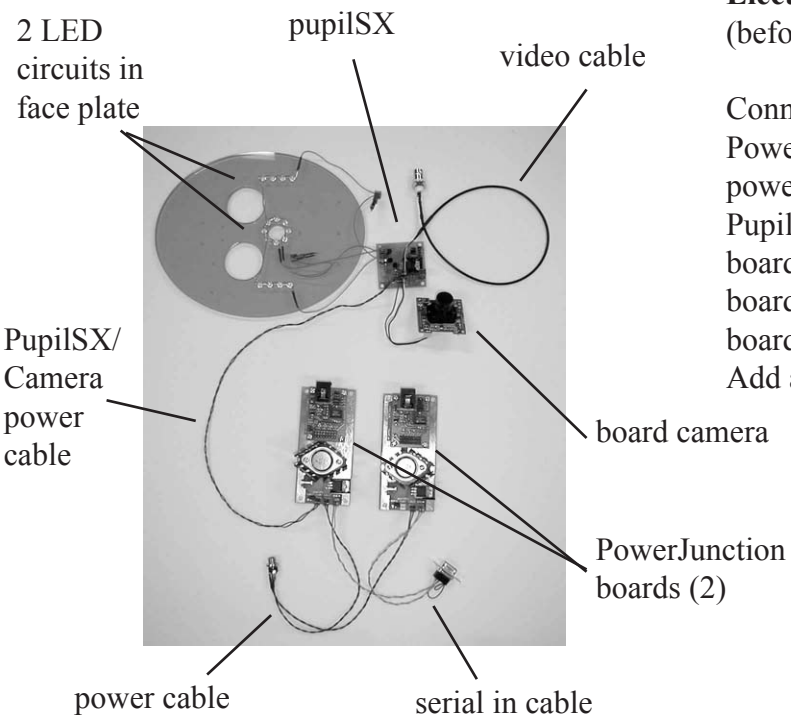




Inner LED cable - use yellow 28-gauge wire and label the MTA connectors "I" (connector to pupilSX header) and "R" (resistor).

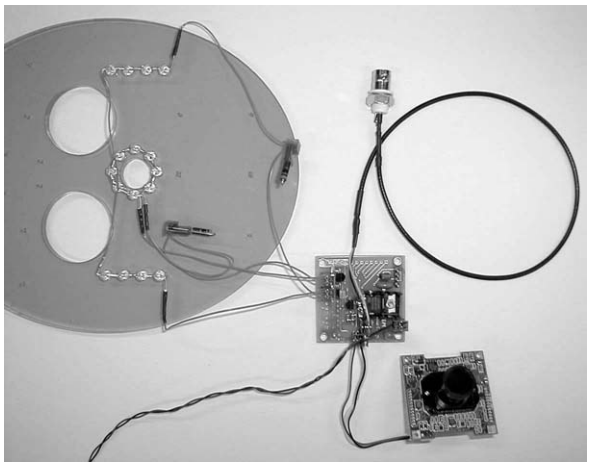


Outer LED cable - use orange 28-gauge wire and label the MTA connectors "O" (connector to pupilSX header) and "R" (resistor).



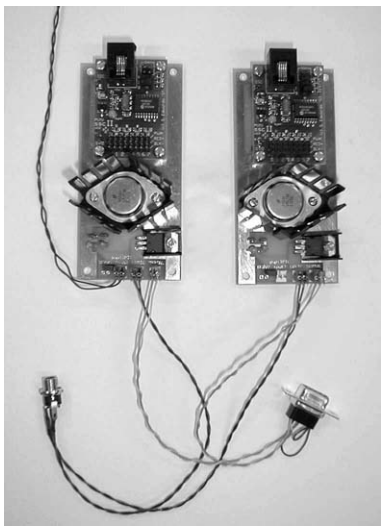
Electronics Test
(before installing elements into PONG)

Connect serial and power cables to their headers on the PowerJunction board. Connect the PupilSX/Camera power cable between the PowerJunction board and the PupilSX board. Connect the camera to the PupilSX board. Connect the video-out cable to the PupilSX board. Attach the LED cables between the PupilSX board and the two 8-LED circuits on the face plate. Add a 38 ohm 2-watt resister to each LED cable.



Camera / Illumination Test

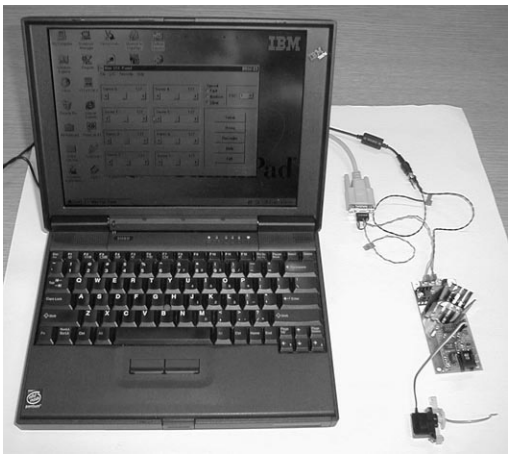
Connect the video-out cable to the framegrabber on the host PC. Insert the plug of a 16VDC ThinkPad power supply into the 5.5mm power jack. Point the camera at the face plate and run the field-differencing software. The inner ring of LEDs should appear bright in only the "inner" field image. Similarly, the two outer bars of LEDs should appear bright in the "outer" field image.



Servo Control Test

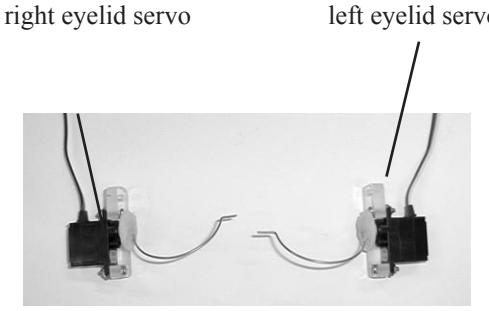
Connect one of the standard TS-53 servos to the servo connection header labeled "0" on the first (0-7) SSCII board. Using a standard RS-232 serial cable, connect the DB-9 connector to an available serial port on the host PC. Run the SSCII sample program and test the function of the servo by moving the slider for servo 0. (Note: keep this setup for the next "servo preparation" step)

V. SERVO PREPARATION



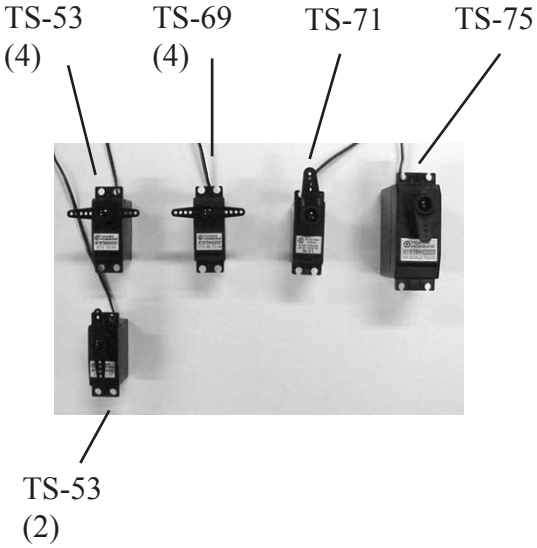
Reset servos to "start" position

Setup the "left" PowerJunction board (SSCII controls servos 0-7). Connect the serial cable between the PowerJunction board and the PC. Connect the power cable to the PowerJunction board and plug in a ThinkPad power supply. Each servo can now be connected to the "servo0" position on the SSCII board. Using the "miniSSCpanel" application, each servo can be reset to the desired position (127 decimal, or mid-position for all servos except the eyelid servos).



The TS-15 eyelid servos are treated slightly differently. Label the servos "L" and "R." Unlike all the other servos, the reference position for the eyelid servos is the "full down" position. For the left eyelid servo this will be decimal value 254. For the right eyelid servo the value is 00.

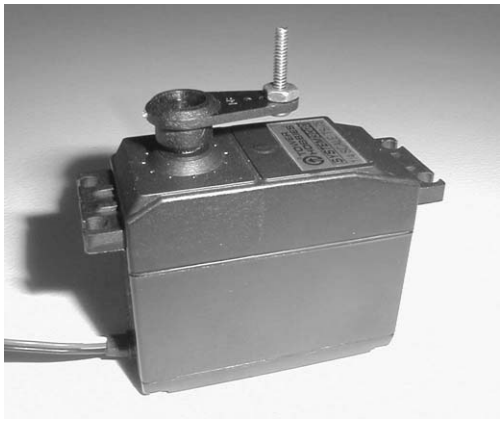
Mount servo arms



After setting each servo, attach the servo arms in these positions:

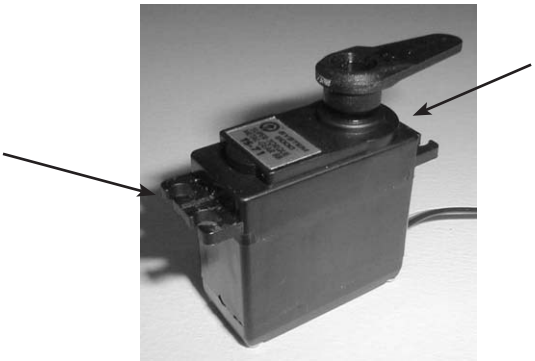
Four TS-53 servos
(two lip corner servos and two eyebrow servos)
Two TS-53 servos
(upper and lower lip servos)
Four TS-69 servos
(eye servos)
TS-71 servo with 1" DUBRO arm
(neck elevation servo)
TS-75 servo with ¾" DUBRO arm
(neck azimuth servo)

The TS-75 servo arm requires an additional modification. Drill out the last hole in the ¾" DUBRO servo arm with a #35 drill bit.



Attach a 5/8" 4-40 bolt and nut in this configuration and mount the servo arm assembly on the TS-75 servo (This bolt will act as a pin that will pass up into the base of the neck assembly and will cause the neck and head to turn from side to side).

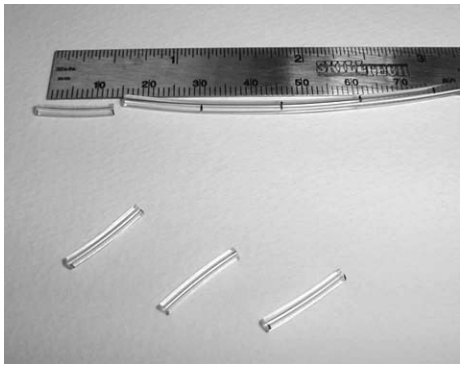
Modify TS-71 servo



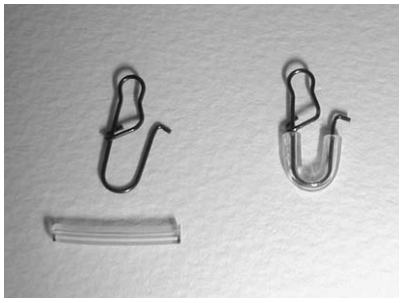
The TS-71 servo is modified by removing the thin ribs on the upper surface of the mounting brackets. This will allow the servo to be mounted flush against this surface of the mounting brackets.

Build control line attachment tackle

To attach the control lines to the servo arms, the following "control-line tackle" is assembled and added to the outer-most holes of each servo/servo arm. Generally, all of the servos in the head block (eyes, eyebrows and lips) use the following "cushioned snap" built in the following way:



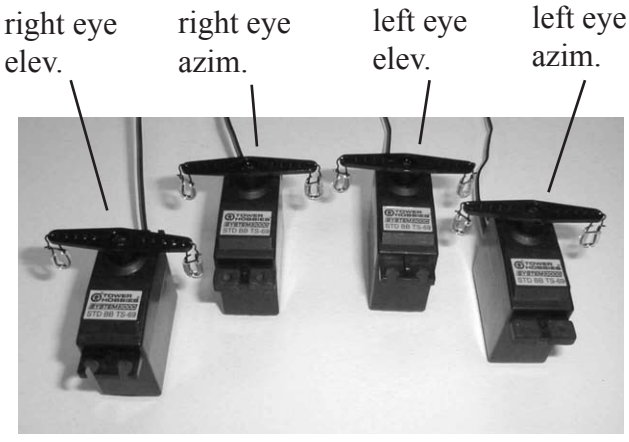
Cut the 1/32"I.D. Tygon tubing into sixteen 15mm lengths.



Thread the Tygon tubing onto the larger wire loop of the #2 locking (fishing tackle) snaps. The tubing acts as a cushion and eases the tension on the nylon control lines by creating a slightly larger radius.

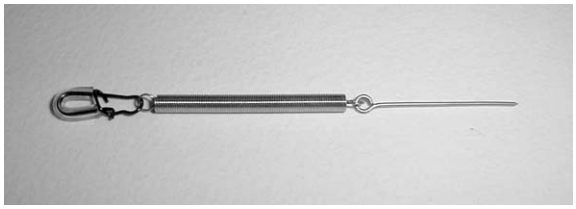
Eye servo tackle

Each of the four TS-69 "eye" servo is configured with two ["cushioned" snap] connectors.

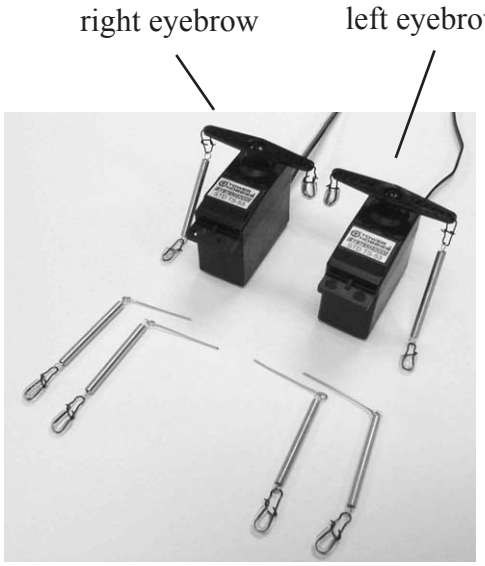


Eyebrow servo tackle

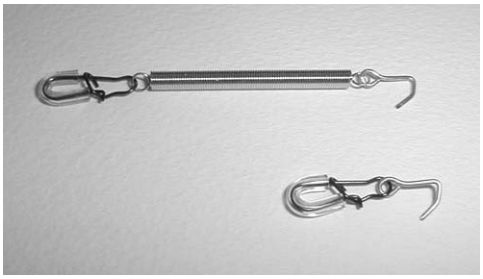
The two TS-53 “eyebrow” servos are configured with one [cushioned snap] connector and one [snap]-[spring]-[cushioned snap] connector.



In addition to these connectors, each eyebrow requires two additional spring connections to anchor the middle and outside points of the eyebrow. The straight wire part of these pieces can be bent out of 22-gauge steel wire and should be at least 1” in length.

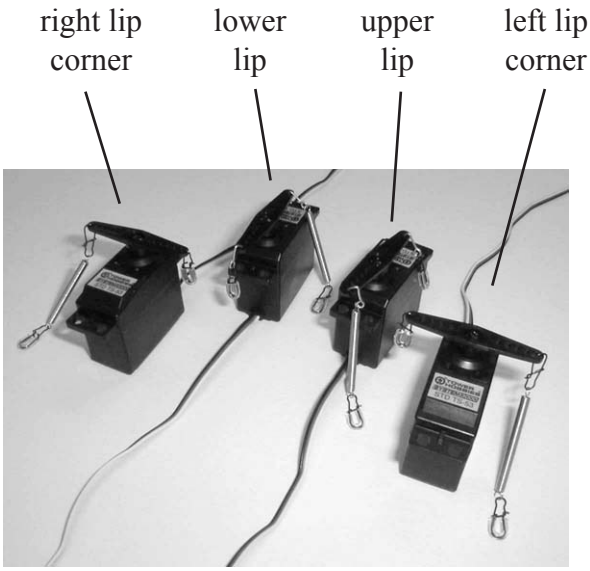


Lip servo tackle



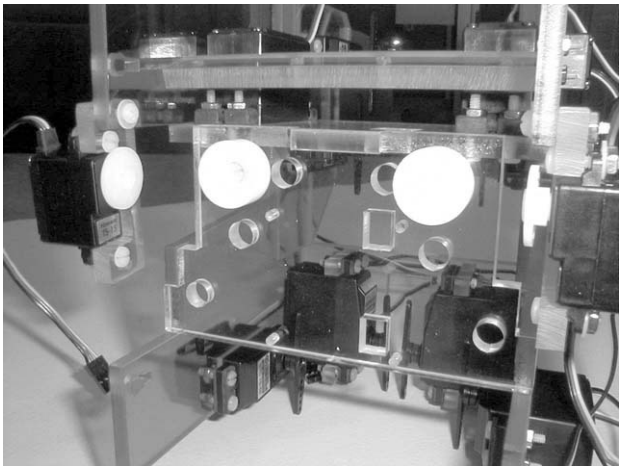
The upper and lower lip servos require a hook-type connection to allow the control lines to be unhooked from the servo arms to allow the head block to be removed from the neck/base (the control lines for the upper and lower lips pass through the center of the neck braces). The hooks can be bent out of 22-gauge steel wire.

The upper and lower lip TS-53 servos (NOTE: the arms on these servos are mounted in this position) have one [hook]-[cushioned snap] connector and one [hook]-[spring]-[cushioned snap] connector.



The four lip servos. Notice that the two lip corner TS-53 servos each have one [snap]-[spring]-[cushioned snap] connector and one [cushioned snap] connector.

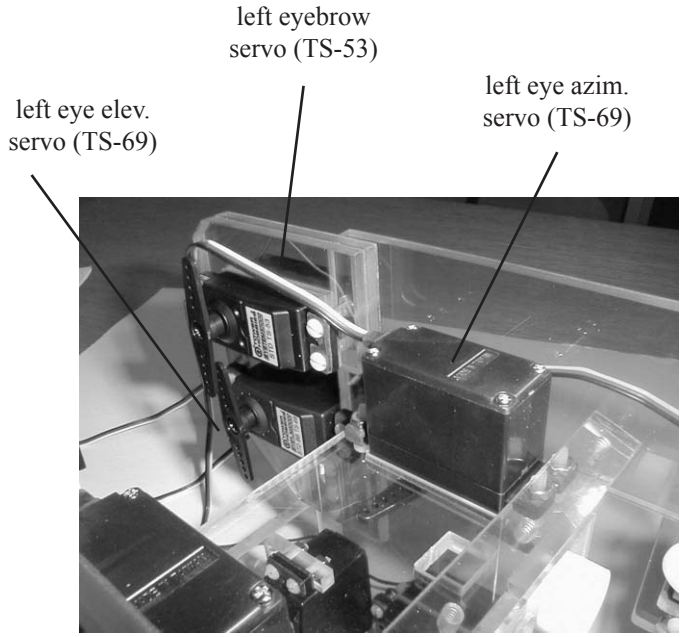
VI. HEAD BLOCK ASSEMBLY



Mount eye sockets

Attach the two teflon eye sockets to the eye socket/ camera plate of the head block with two ½" nylon 4-40 bolts and nuts.

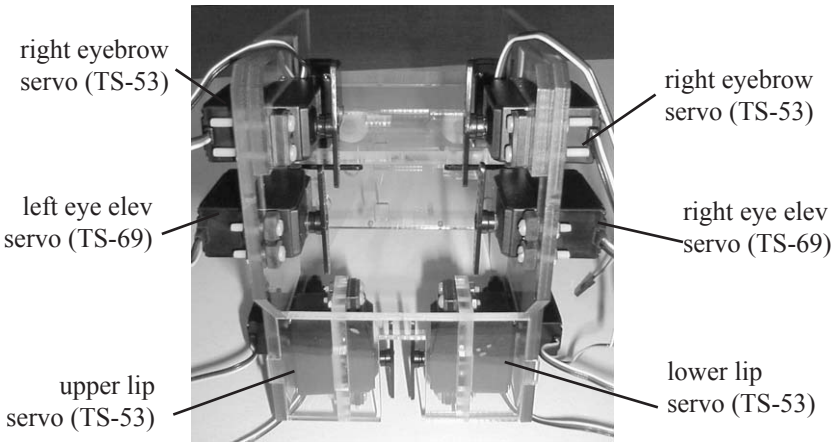
Mount servos in headblock



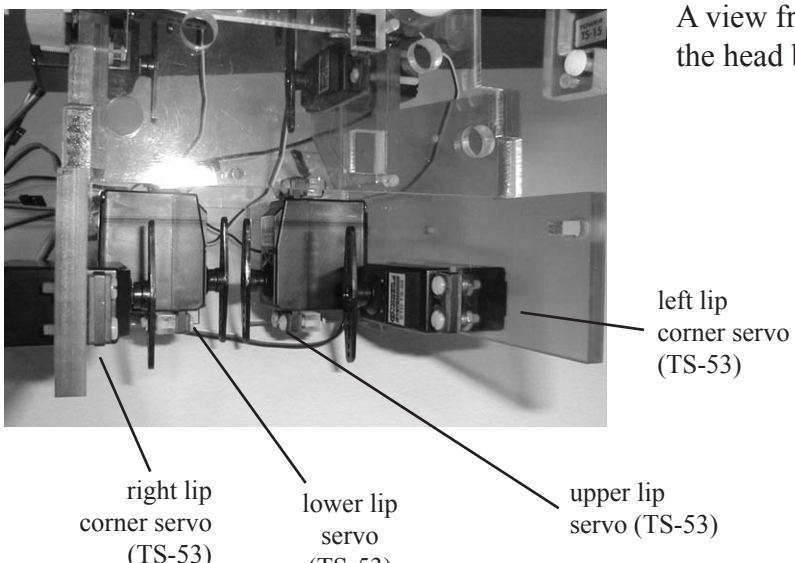
Mount the four TS-69 (eye servos) and the six TS-53 servos (mouth and eyebrow servos) in these positions in the head block. Attach the rubber mount "covers" to the servos (included with the servo from the manufacturer) and use 5/8" or 1" 4-40 bolts and nuts to attach the servos to their mounts in the acrylic head block.

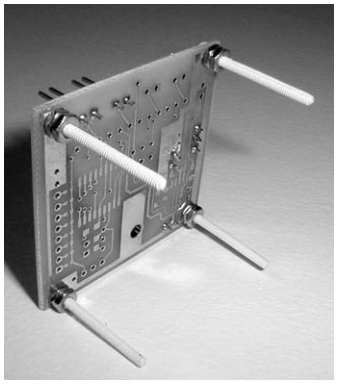
A view from the front looking down into the head block. Note the mounting position of the left eye azimuth servo with the mounting brackets of the servo on the top surface of the "base" plate and the servo arm below the base plate.

A view from behind the head block.



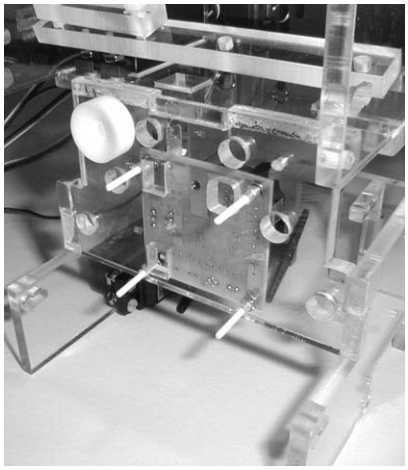
A view from the front looking into the lower half of the head block. These are the four "lip" servos.



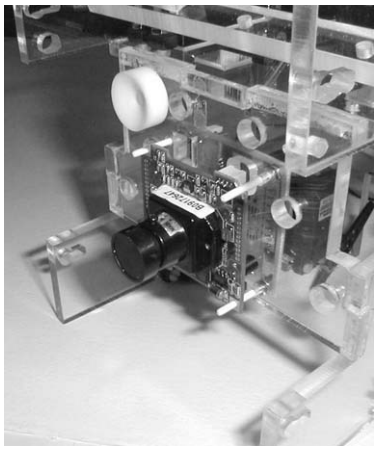


Mount camera and pupilSX board

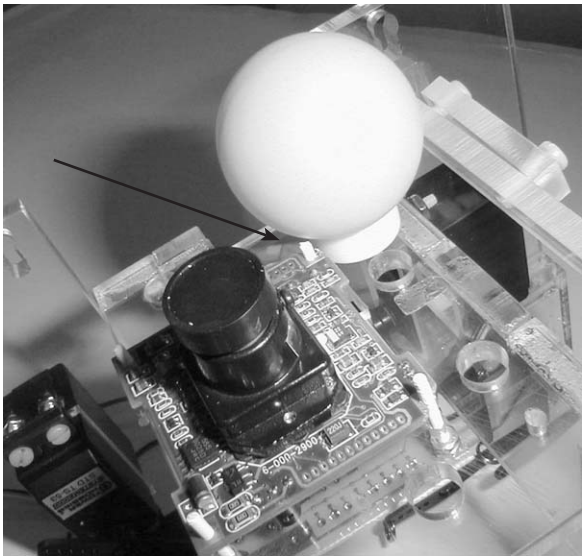
PupilSX and Camera
Attach four 1” 2-56 nylon bolts to the pupilSX board. The four bolts should stick out toward the back of the board and two nuts can be added to each bolt to act as spacers.



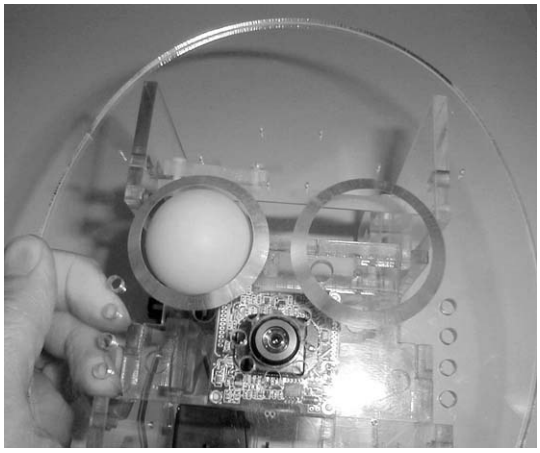
Insert the pupilSX and bolts into the four holes in the eye socket plate of the head block (with the camera connection header on the pupilSX pointing up). The pupilSX is inserted from behind the eye socket plate with the four bolts protruding through and pointing towards the front. Add four nuts to hold the pupilSX in place against the eye plate.



Loosely mount the board camera on the four protruding bolts.

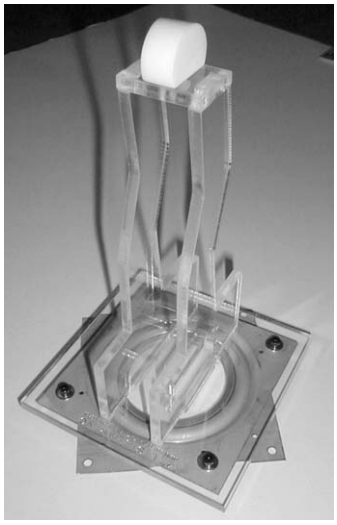


Using a ping pong ball, attempt to move the camera as far forward and still allow clearance for the eye to move freely in its socket. The upper corners of the board camera can be ground away but be careful not to destroy any components or traces on the board. The bottom corners of the camera can be secured with bolts. The upper corners can be secured by adding bolts at the desired spacing, clipping the ends of the nylon bolts (flush to the front of the board camera) and using a small dab of adhesive (hot glue) to hold the board camera onto the bolt/nut.



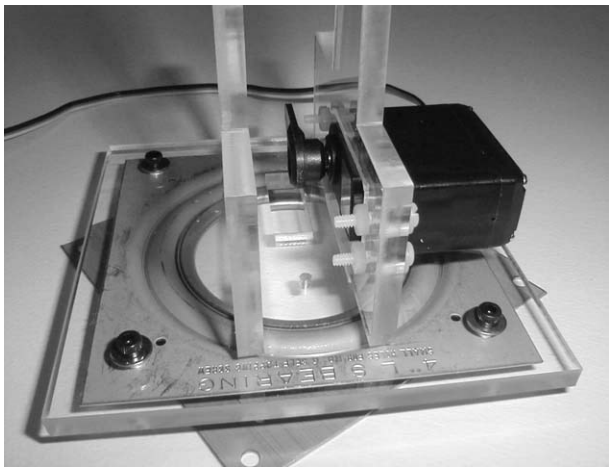
Finally, test the fit of the eye/camera configuration by loosely holding the face plate in its position and height away from the head block.

VII. NECK ASSEMBLY

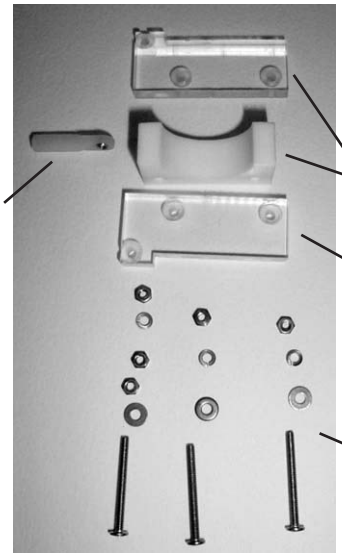


Attach the teflon neck joint to the top plate of the neck assembly with two ½" 4-40 nylon bolts. The teflon joint part has two 4-40 threaded holes that should align with the two holes in the top plate of the neck assembly.

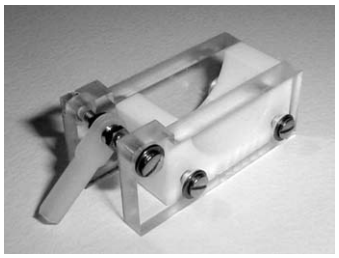
Attach the ball-bearing turntable to the bottom plate of the neck assembly with four ½" 6-32 socket head bolts and four 6-32 locknuts.



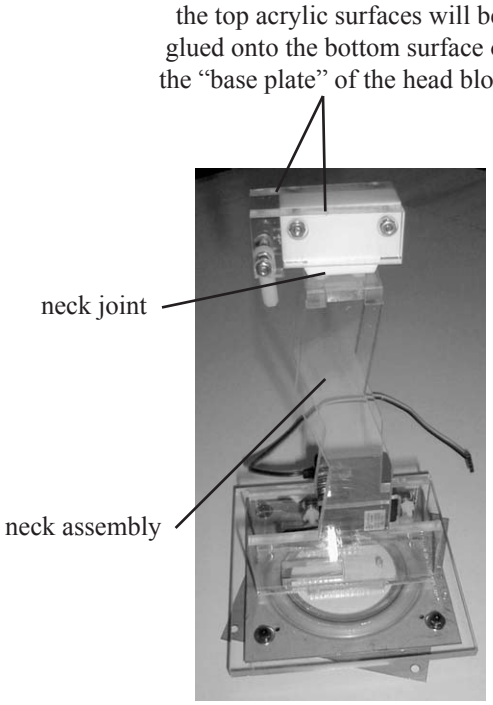
Install the TS-71 neck azimuth servo in its mount on the left side of the neck assembly with ??" 4-40 bolts and nuts. NOTE: the TS-71 is mounted with its servo arm pointing toward the rectangular hole in the bottom plate (towards the rear) and with the upper surfaces of its mounting brackets flush against the acrylic side plate.



These are the parts of the “neck saddle assembly. The neck saddle assembly sits on top of the semi-circular neck joint and will eventually be glued onto the “base plate” of the head block.

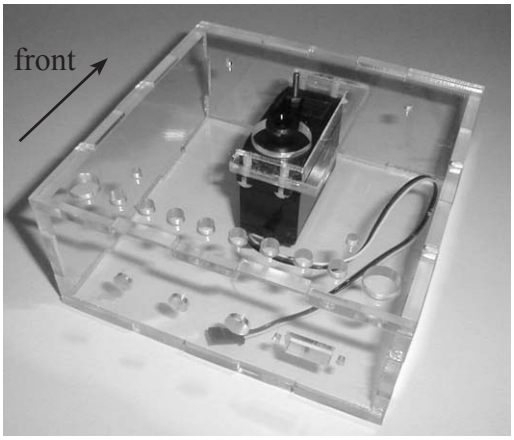


Completed neck saddle assembly. NOTE: it may be required to remove some material from the top surface of the teflon saddle part to allow good gluing contacts between the acrylic side plates and the acrylic plate in the head block.



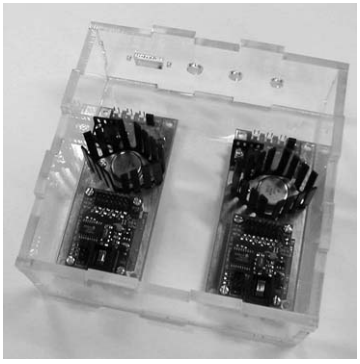
Test fit the complete neck saddle assembly on the teflon joint on top of the neck assembly. NOTE: some material may need to be removed from the sides of the teflon joint (on the top of the neck assembly) to allow smooth low-friction movement.

BASE BOX ASSEMBLY

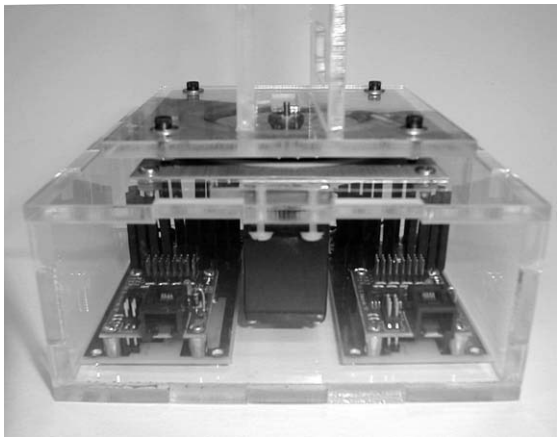


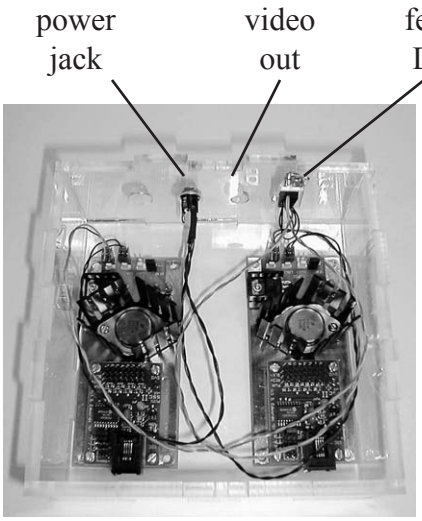
Install TS-75 and PowerJunction boards

Install the TS-75 servo in top plate of base box with four 6-32 nylon screws and four #6 washers. The TS-75 servo is mounted on its mounting bracket on the bottom surface of the base box top plate. The ¾" arm and "pin" are inserted up through the center hole in the top plate (Note it may be necessary to temporarily remove the servo arm but care should be taken to reattach it in the same "midpoint" position).

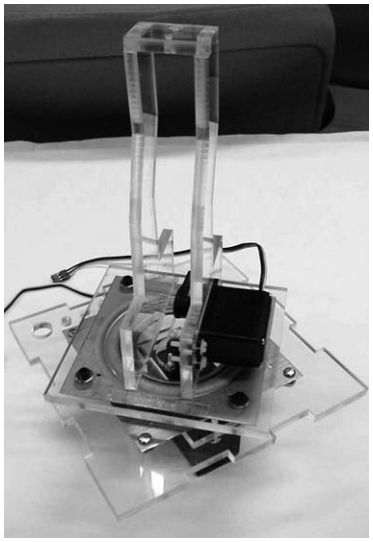


Install the two power junction boards on either side of the TS-75 servo (flush against the sides of the base box) with their connection pins pointed toward the back plate of the base box. Use double-sided mounting tape applied to non-trace areas of the bottom of the power junction board.





Mount the DB-9 housing (serial in), the BNC bulkhead (video out, not shown in this picture) and the 5.5mm power jack (power in) into the back plate of the base box. Then connect the cables to the two power junction boards for 1) power in, 2) serial in, and 3) camera/pupilSX power out (this is a single cable and can be connected to either power junction board). The loose connectors on the camera power cable and the video out cable will both later be routed up into the head block and connected to the pupilSX board.

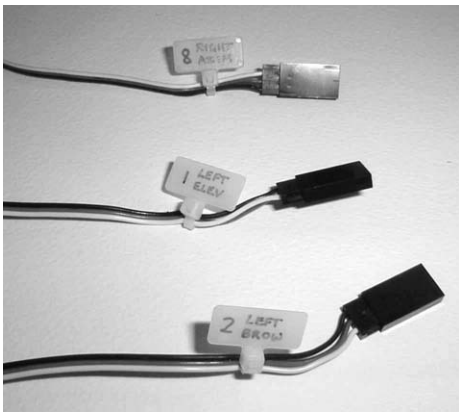


Install neck assembly on top plate

Attach the neck assembly (with the turntable attached to its base) to the top plate of the base box with four ½" 6-32 flathead steel bolts and four 6-32 lock nuts. NOTE: the "pin" on the end of the TS-75 servo must be aligned and inserted into the hole in the base plate of the neck assembly.

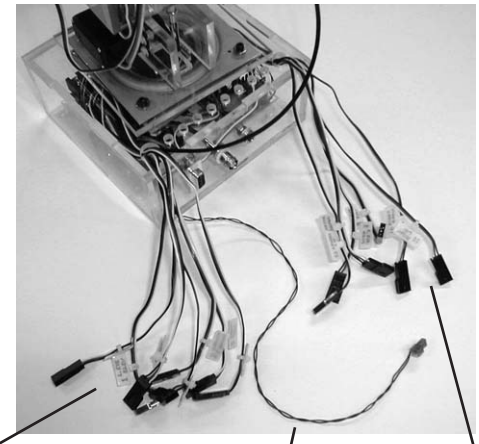
Label servo extension cables

Label the 6" servo extension cables using small nylon ties with flags:



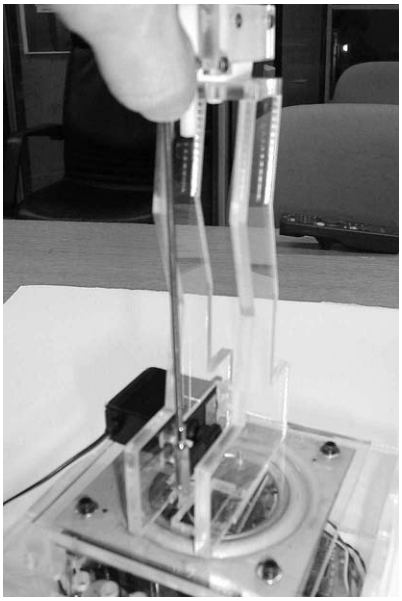
(SSCII #1 controls servos 0 - 7)
0 - left eye azimuth
1 - left eye elevation
2 - left eyebrow
3 - left lip corner
4 - upper lip
5 - neck elevation (tilt)
6 - left eyelid
7 - (not used)

(SSCII #2 controls servos 8 - 15)
8 - right eye azimuth
9 - right eye elevation
10 - right eyebrow
11 - right lip corner
12 - lower lip
13 - neck azimuth (pan)
14 - right eyelid
15 - (not used)



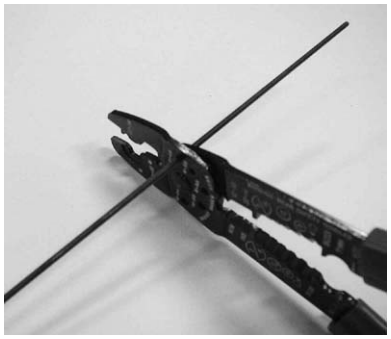
Route cables through the two large holes and connect to correct positions on SSCII boards.

Close base box.



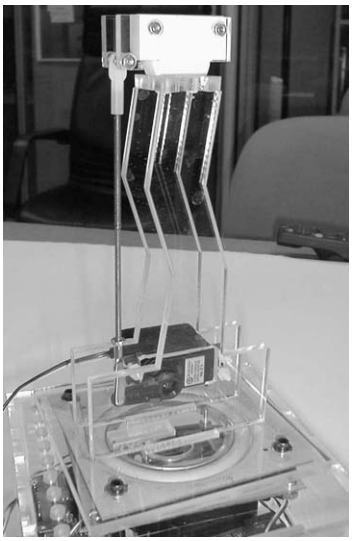
Mount neck saddle on neck assembly

Screw the 4-40 threaded pushrod into the steel clevis on the end of the neck elevation servo (in the neck assembly). With the Neck Saddle Assembly in its socket and level on the Neck Assembly, hold the push-rod up next to the nylon swivel ball clevis on the neck saddle assembly. Mark the pushrod allowing for about ¼" to be threaded into the nylon clevis.



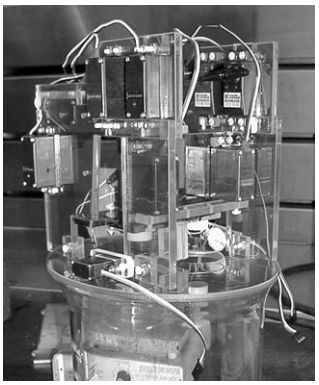
Remove the steel clevis from the neck elevation servo. Using cable cutters, cut the pushrod at the mark. If necessary, clean up the cut with a file or with a grind-ing wheel.

Screw the cut end of the pushrod into the nylon swivel ball clevis on the neck saddle assembly.



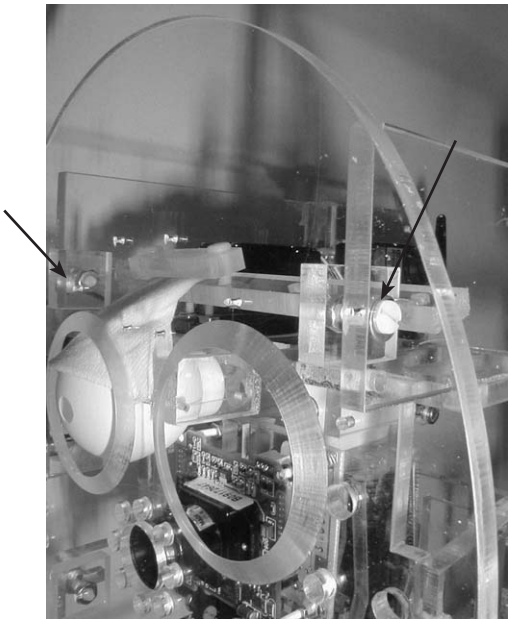
Reattach the steel clevis onto the neck elevation servo and test the length of the pushrod. Adjust the length until the top surface of the neck saddle assembly is level (the neck elevation servo should still be at its mid-point position with the servo arm level).

IX. FINAL HEAD BLOCK ASSEMBLY

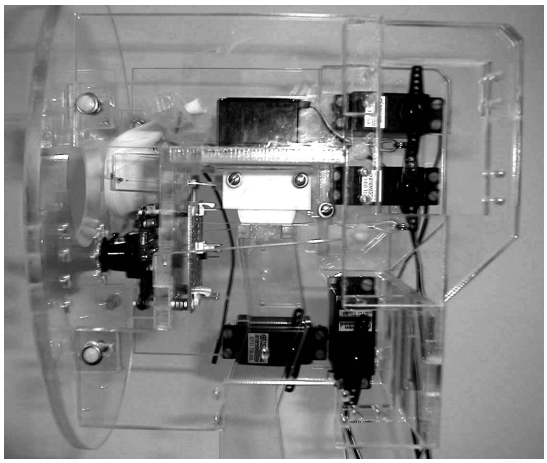


Attach faceplate mounts

Attach the face plate mounts (small rectangular acrylic parts with a hole near the center) to their mounting positions on the head block with four ½" 4-40 bolts and nuts. Do not over tighten these mounts to allow adjustments in the height of the face plate away from the head block. Carefully align the face plate with the features in the head block and adjust the mounts to insure good contact with the back surface of the face plate. When satisfied with the alignment, use acrylic solvent to carefully glue the mounts to the face plate. When dry, the face plate and the mounts can be removed from the head block by removing the four bolts and nuts.



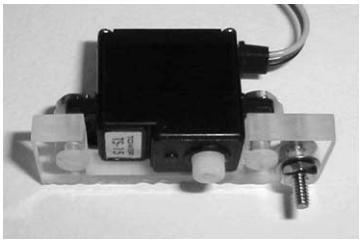
Mount head block to neck saddle



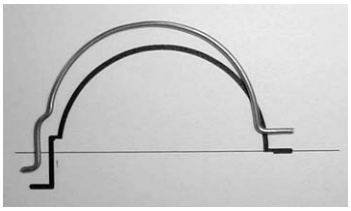
With the faceplate attached, place the head block on the complete base box/neck/neck saddle configuration. While holding the head block so that the base plate of the head block is resting on the top surface of the neck saddle assembly, move the head block backward and forward to find a good balance point. When satisfied with the balance, mark the position of the saddle block on the base plate with a fine-tipped marker. Lift the head block off and remove the face plate. Place the head block up-side-down on a flat surface. Remove the neck saddle assembly from the neck assembly and, using the reference marks, reposition it on the base plate of the head block. Attach the neck saddle assembly to the bottom surface of the head block base plate with acrylic solvent/cement.

X. CONSTRUCT FACE FEATURES

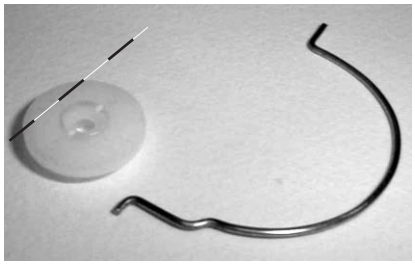
Eyelid Assembly



Mount the TS-15 micro servo in the acrylic eyelid servo mounting bracket with two ??" 4-40 bolts and nuts. Note the orientation of the servos and brackets for the left and right sides.

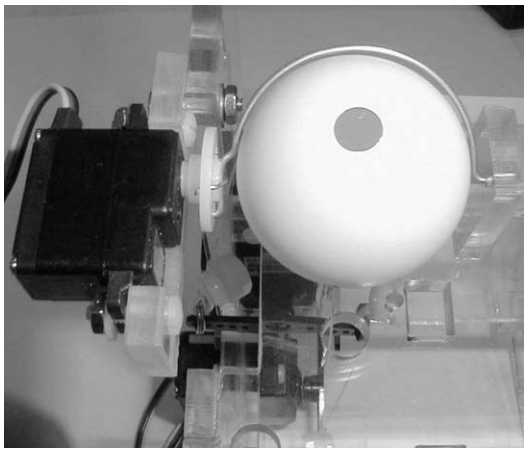


EYELID WIRE
Bend 18 gauge wire to fit the shape of the included "eyelid wire template."

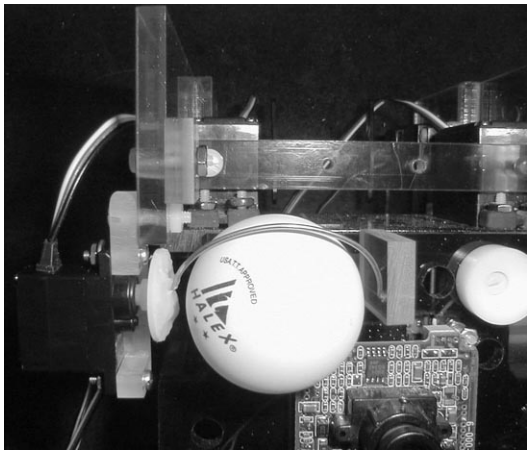


Modify the small white servo disc (included with the TS-15 as an alternative to a servo arm) by cutting a notch in the raised circle on its "outside" face. The notch should be aligned with two sets of holes and just large enough to accept the 18 gauge wire diameter.

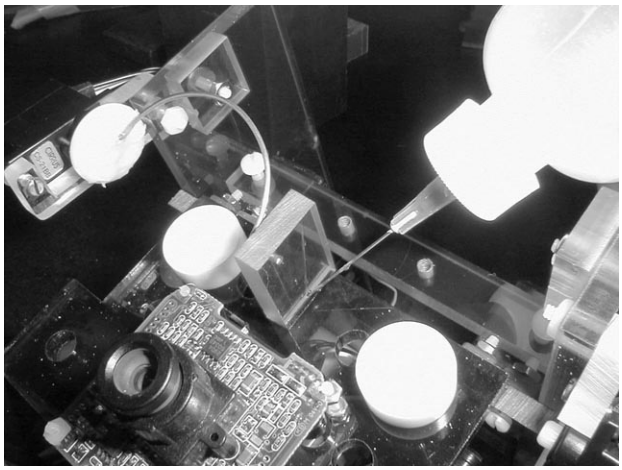
The eyelid wire is then mounted in this notch with the 90-degree bend inserted into one of the aligned holes in the servo disc. The assembly can then be strengthened by adding a short length of 22-gauge wire across the eyelid wire and inserted into other holes in the servo disc.



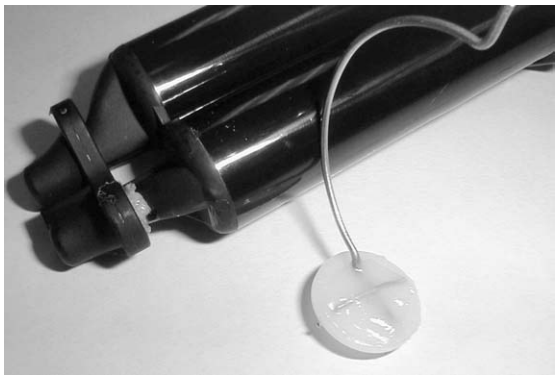
The eyelid wire should then be tested for shape and clearance by mounting the complete eyelid assembly on the head block and using a loose ping pong ball.



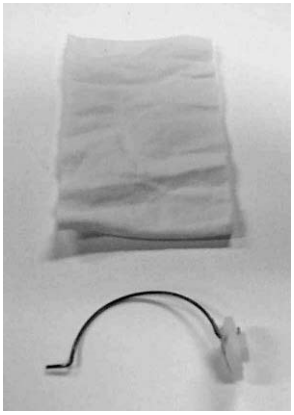
Mount the eyelid servo bracket on the head block side plate with a 1/2” 4-40 screw, washer and nut. Using a ping pong ball and the (unattached) eyelid post, adjust the brackets position for good alignment with the ball and post. When satisfied tighten the screw and nut.



Use acrylic cement to glue the eyelid post in place on the socket/camera plate.



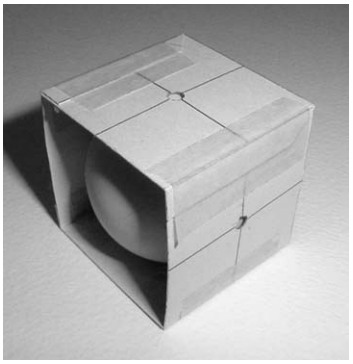
When satisfied with the eyelide wire shape and fit, the eyelid wire/servo disc assembly can be further strengthened by applying plastic welder cement.



EYELID MATERIAL
Cut a 2 to 2 1/8 inch “tube” of material from a nylon panty hose.

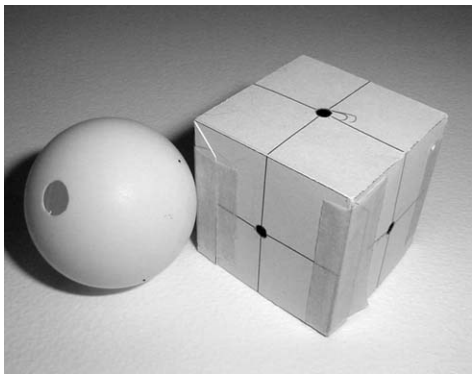
Apply rubber cement to the eyelid wire and allow it to become tacky.

Insert the eyelid wire into the nylon tube and stretch the nylon material over the full arc of the eyelid wire. Hold until dry.

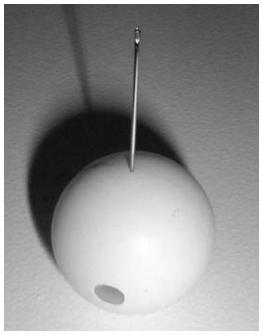


Eyeballs

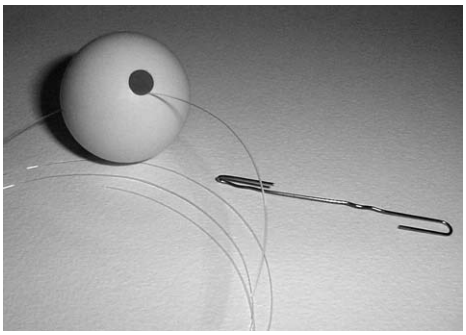
Cut out and assemble the “eyeball template box.” Carefully hold a ping pong ball in the box and mark the five points using a fine-point marker.



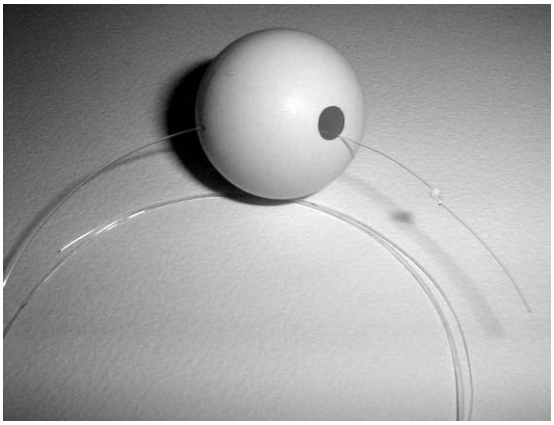
Drill out the “center” mark with a ¼” drill bit. This will serve as a “pupil” and allow the attachment of the four “control lines” to the other four positions on the eyeball.



Puncture the other four marks with a sharp sewing needle.

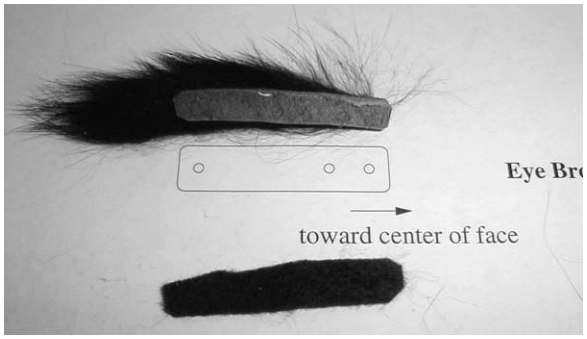


Cut an 18” length of fishing line and thread one end into a needle hole. Using a paper clip “hook” reach into the interior of the ball through the pupil hole and pull the fishing line out through the pupil.



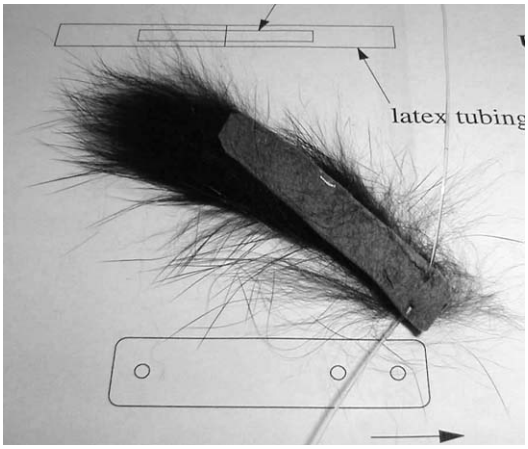
Thread a small bead onto the line coming out of the pupil and tie off the end of the fishing line with a simple stop knot. When the bead and knot are pulled back through the pupil hole they will stop firmly against the inside surface of the ping pong ball and provide a simple attachment that will work well under constant tension.

Repeat this procedure for the other 3 control lines.

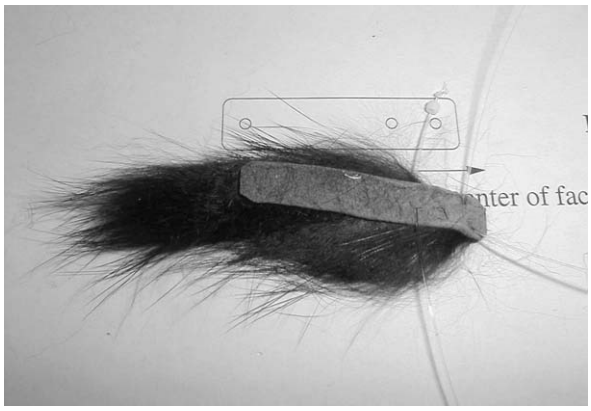


Eyebrows

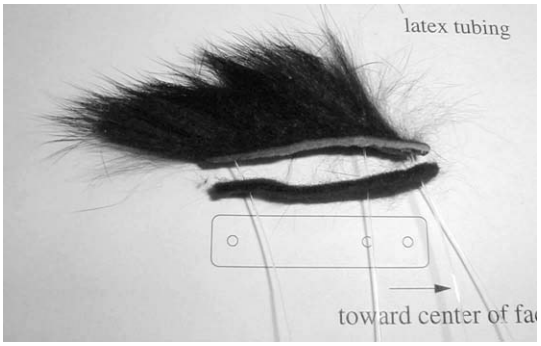
Cut a 42 mm length of black fur strip (set the eyebrow template). Cut a matching strip of black felt.



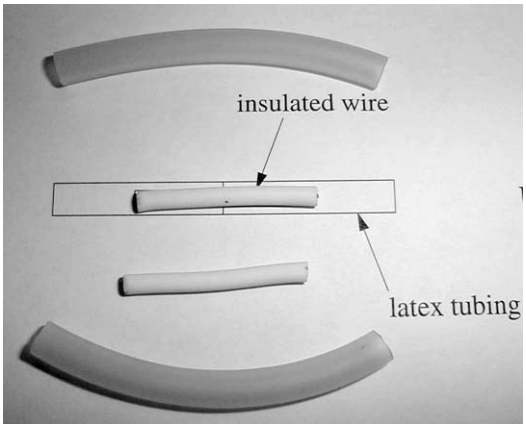
To attach the inside eyebrow control line (towards the center of the face), thread a 30” length of fishing line onto a needle and push the needle from the back of the strip through a point slightly off-center from the “inside” mark on the eyebrow template. Pull about half the length of the line through. Tie a small bead onto the line at this half-way position. Thread the line onto the needle again and pass it through the strip from the front. Pull the two lines coming out of the back of the strip until the bead is held against the front of the fur strip (the bead will be hidden in the hairs of the fur).



To attach the middle eyebrow control line, thread a second length of fishing line (at least 15” long) onto the needle and pass the needle through the strip at the position indicated on the eyebrow template from the back of the fur strip. On the end of fishing line sticking up through the front of the strip, add a small bead and tie off the line with a simple stop knot. Pull the line from the back until the bead is held against the front of the strip. Repeat this step for the “outside” control line (farthest away from the center of the face).

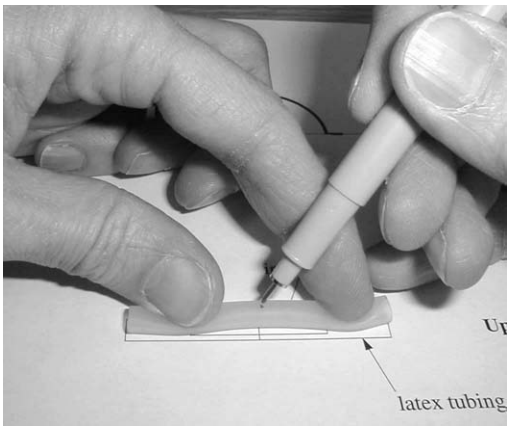


Thread the three control lines through the felt pad by poking the lines through the felt at the corresponding positions. The felt pad provides a soft low-friction surface that will move smoothly over the acrylic face plate.

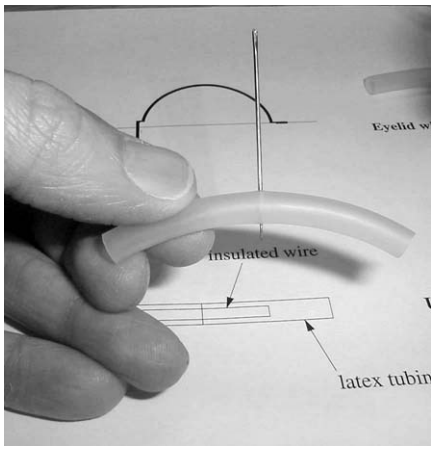


Lips

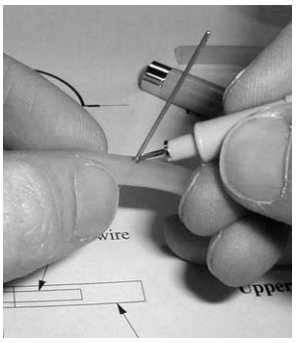
Using the Lip Template, cut two lengths of latex tubing and two lengths of the white insulated wire (the wire will be inserted into the tubing to stiffen the tubing and provide a smoother bend when the center of the lip is pulled up/down).



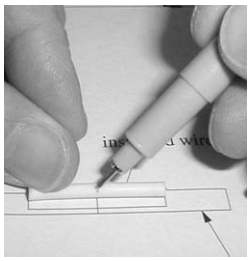
Mark the center of the rubber tubes using a fine marker.



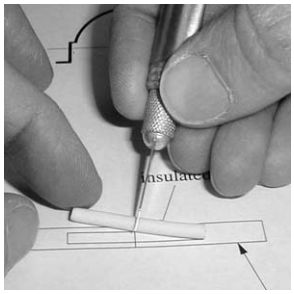
The rubber tubing will usually have a natural curve. Observing this curvature, pass a needle through the tubing at the center point so that the two ends bend down flat relative to the needle.



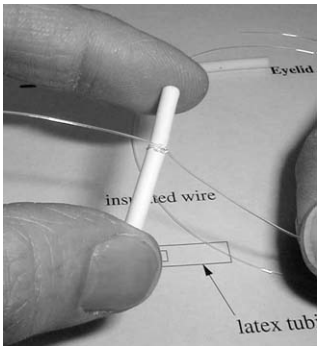
Leave the needle in the tubing and carefully mark the top and bottom points where the needle passes through the tubing (draw a small circle around the shaft of the needle). This will aid in finding the holes once the needle has been removed.



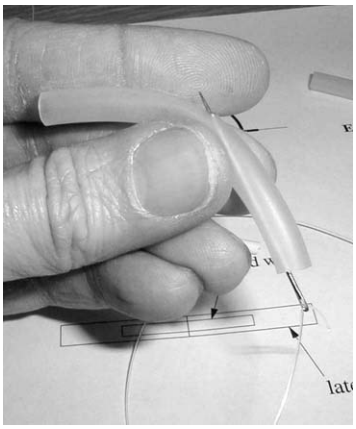
Mark the center of the insulted wires.



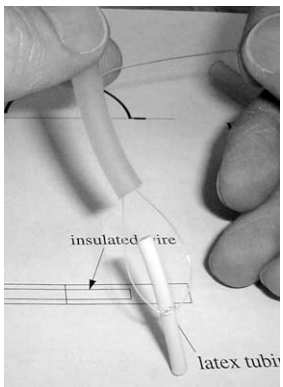
Carefully score the insulation around the diameter of the wire (try not to damage the wire).



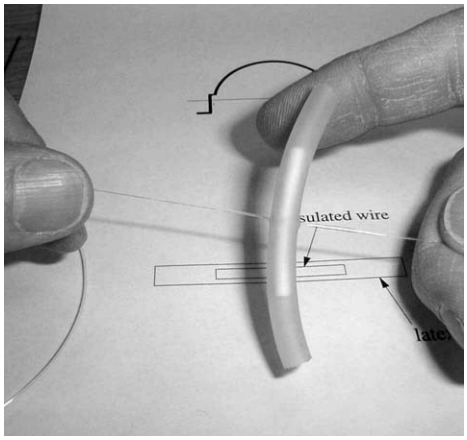
Cut a 30” length of fishing line. Find the center of the line and tie it around the insulated wire at the scored groove.



Thread one of the ends of the fishing line onto a needle and pass it through the end of one of the tubing pieces. Carefully push the needle from the inside of the tubing through one of the previously marked “holes.”

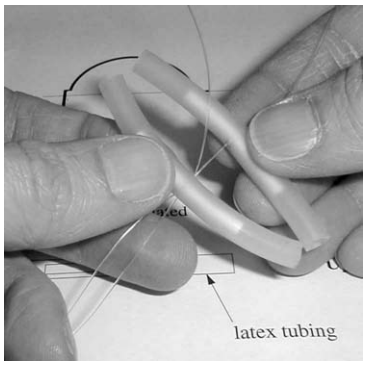


Repeat this with the other end of the fishing line. Pass the needle through the same open end of the tubing used in the previous step and push it through the second “hole.”

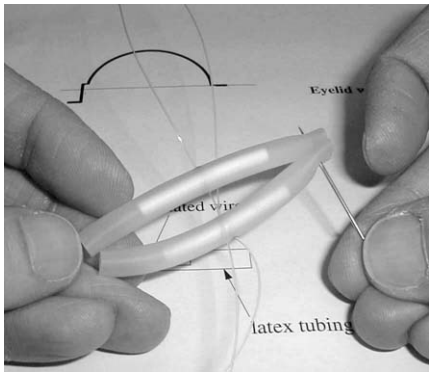


Pull the two lengths of line through the holes until the wire is almost at the open end of the tubing.

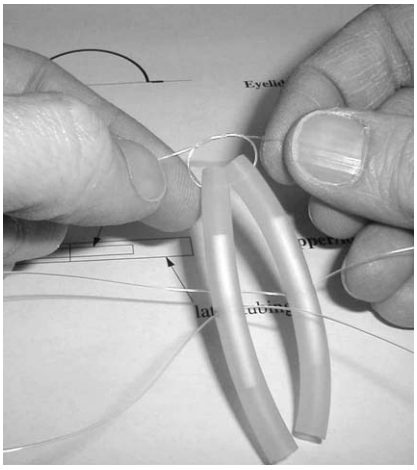
Carefully pull on the lines and guide the wire into the tubing until the wire is centered inside the tubing.



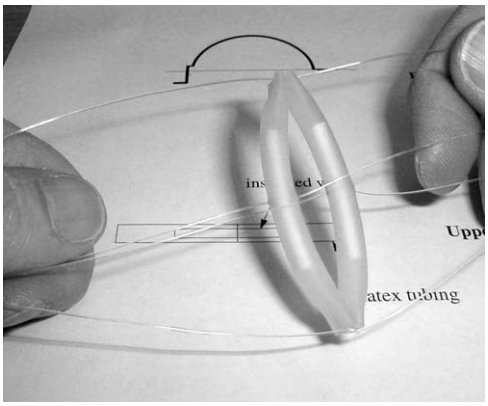
Repeat this step for the other lip. When both lips are complete, hold the two lips so that the curvature of two lips are oriented towards each other.



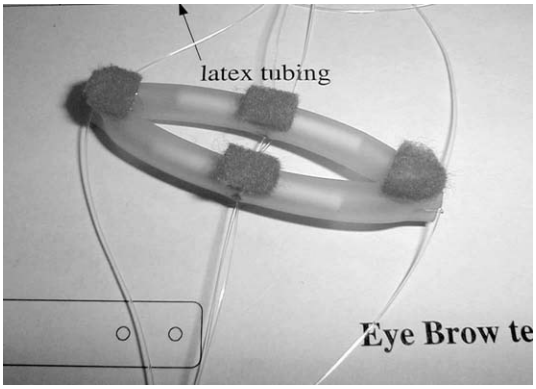
While holding this configuration, pass a needle through both tubes at one of the "mouth" corners. Thread a 30" length of fishing line on the needle and pass it through the lips.



Near the center of the line, tie a square knot to pull and hold the two lip ends together. Be careful not to pull too tightly as to tear the wall of the tubing.

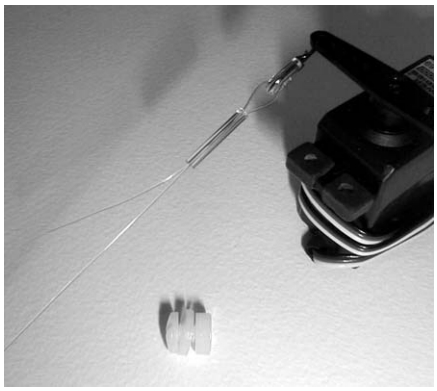


Repeat this step for the other mouth corner. The completed mouth will look like this.



Apply four small felt pads at these positions on the back side of the mouth. Use a glue or epoxy that adheres well to rubber. These pads will allow the lips to move smoothly over the acrylic face plate.

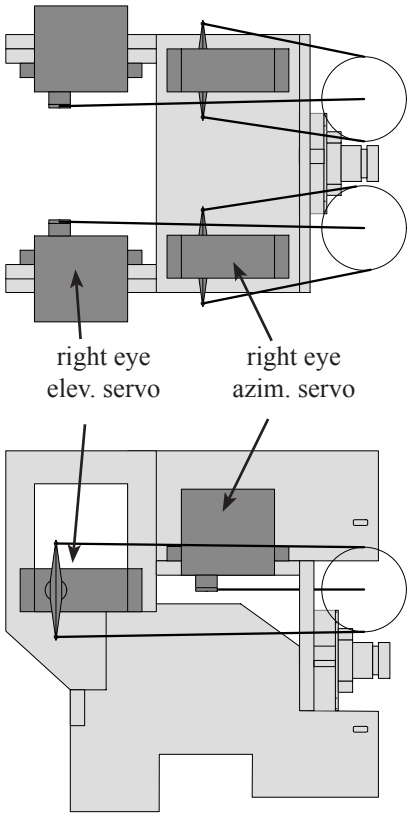
XI. FINAL ASSEMBLY



Attachment of Control Lines to Servo Arms

The general method for attaching the control lines to the servo arms is to pull the line back to its servo arm, pass the line through a short length of Tygon tubing (15mm), pass the line around the "cushioned snap" on the servo arm and thread the line back through the Tygon tubing a second time. The inside diameter of the Tygon tubing is 1/32" and will allow just enough room to pass a 0.015 diameter line through twice. When a small clamp is applied to the outside of the tubing, a tight but adjustable connection can be made.

NOTE: The installation of the face features is made easier by removing the head block from the neck/base. Once the face features are installed and adjusted, the head block can be reinstalled by unhooking the upper and lower lip control lines. After the head block is attached to the neck, these lines are then reconnected.

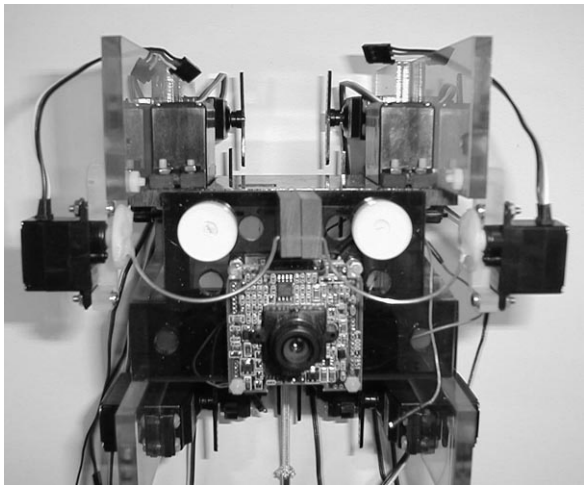


Install eyes

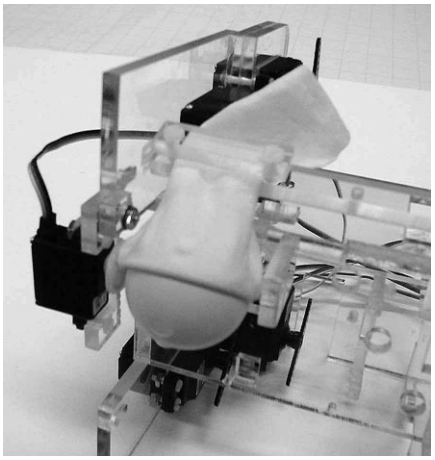
Before installing the eyes and eyelids, remove the faceplate and set it aside.

Eyes
The two top and bottom lines on each eye are pulled back and attached to the corresponding eye elevation servo. The side lines are attached to the eye azimuth servos.

Install eyelids



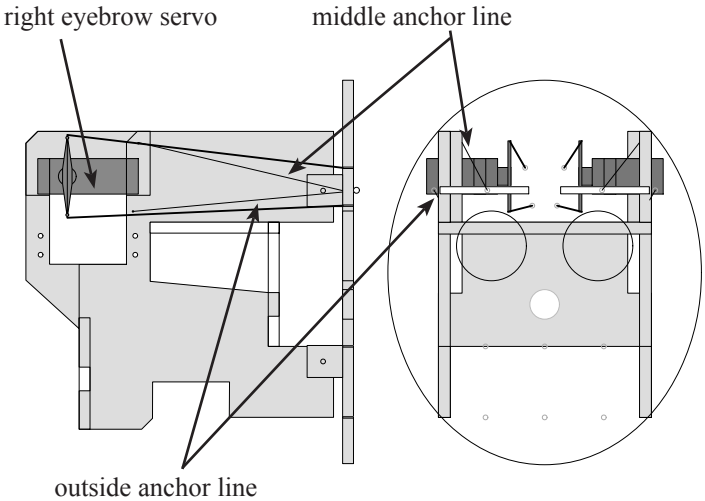
With the eyelid servos in their “full down” position, match the left and right eyelid disc/wire assemblies. Note it may be necessary to loosen the servo mounting screws to reposition the disc on the servo pin. (Note that the eyes and the nylon “eyelid” material are not shown in this photo)



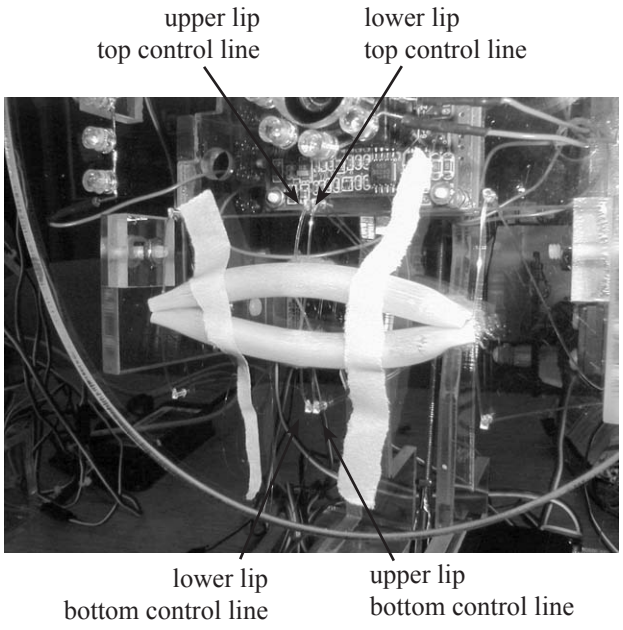
Final eyelid assembly mounted in head block. The loose end of the nylon is pulled back and held in the eyelid clamp bar in the head block. Use the small clamp block and two 1/2” nylon 6-32 screws to clamp the nylon material against the clamp bar. Experiment with the amount of stretch by connecting the eyelid servos to the SSCII servo controller and testing the servo action.

The faceplate can now be reinstalled and adjusted for proper clearance of eyes and eyelids.

Install eyebrows

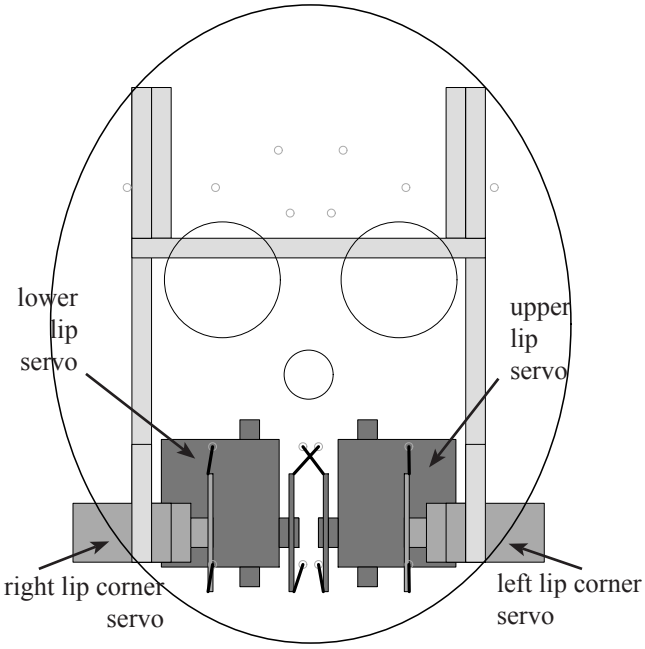


The “inside” control lines for each eyebrow pass back through the face plate and attach to the two ends of the corresponding eyebrow servo. The center and outside control lines are pulled back and attached to the fixed spring connectors. These spring connectors are attached to the head block by pushing the straight wire end through the corresponding hole in the head block and bending the excess over. These connection points allow the eyebrow to move slightly as the inside is pulled up or down.



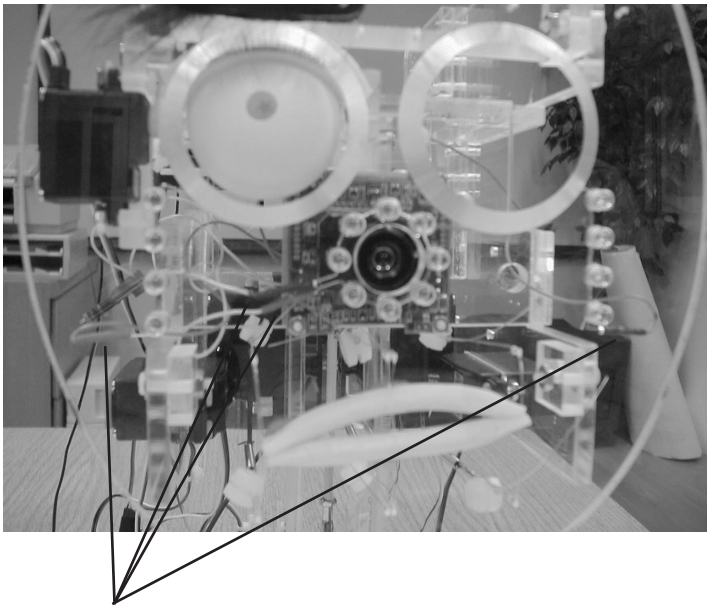
Install lips

The installation of the mouth is the most complex and difficult of the face features. To aid this process, tape the mouth in its neutral position on the front of the face plate. Pass the six control lines through the corresponding holes.



This diagram shows the connection scheme for the mouth control lines. Note that the lines attached to the top of the upper and lower lips cross over each other as they pass back towards their corresponding servo arm attachment points. This crossing of control lines (they cross on the front of the face plate as well) for the center parts of the lips produces less twist in the mouth when the mouth is pulled open.

Re-mount and reconnect head block



LED connections

Connect the LED cables to the corresponding LED circuits on the face plate. Use the red/black marks on the terminal LEDs to get the polarity correct for both the inner “ring” and the outer “bars” circuits. The female ends of the LED cable can be slipped onto the long leads left on the “ends” of the LED circuits.

Disconnect the hooks for the upper and lower lips from their corresponding servo arms. Careful left the head block and place it on the neck saddle joint. Reconnect the neck elevation pushrod by opening the steel clevis and slipping it onto the last hole on the neck elevation servo arm. Reconnect the upper and lower lip control lines. Reconnect the PupilSX power cable and the video-out cables to the back of the PupilSX board.

XII. APPENDIX

Parts and supplier list

Tower Hobbies [towerhobbies.com, (800) 637-4989]

48	TOWM4525	TS53 servo	34.97/3
32	TOWM4545	TS69 servo	48.97/3
8	TOWM5215	TS71 servo	112.97/3
8	TOWM4565	TS75 servo	112.97/3
16	TOWM5245	TS15 servo	82.97/3
80	FUTM1980	servo horn	3.39
8	DUBM6670	DUBRO arms	9.69
8	GPMQ3794	4-40 clevis	1.39/2
8	GPMQ3862	4-40 swivel ball	1.39
96	HCAM2100	extension cables	47.88/12

Jameco Electronics [jameco.com, (800) 831-4242]

25	51334	7812 12V regulator TO-220	0.29
18	23667	LM323K 5V 3A regulator T0-3	3.95
8	151562	2.5mm male power jack	0.89
200	100765	female pin	0.10
16	151001	MiniSSC II servo controller	49.95
8	111561	BNC bulkhead (female)	1.75
8	85542	75 ohm BNC cable (6')	2.95
8	25700	serial cable (6')	4.95
8	114753	RCA-BNC adapter	1.25
8	73197	DE9 female housing	0.39
100	43369	female crimp pins DE9	0.06
8	51182	5V regulator TO-92	0.29
8	158051	TO-220 heatsink	0.29
16	151546	TO-3 heatsink	0.99
20	119423	2N7000 MOSFET transistor	0.29
10	33689	10uF tant. Cap	0.59
10	108337	2-pin header	0.10
10	19140	jumper $0.10	
10	109575	3-pin header	0.10
10	157382	3-pin housing	0.15
10	117559	4-pin header	0.10

DigiKey [digikey.com, (800) 344-4539]

100	A1921-ND	2-pin MTA header	0.10
100	A19132-ND	2-pin MTA housing	0.19
10	LM1881M-ND	LM1881M video sync SO-8	5.11
50	PCC1828CT-ND	0.1uF SMT cap (805)	0.16
50	P680KGCT-ND	680Kohm SMT res (603)	0.076
50	P10MGCT-ND	10M ohm SMT res (603)	0.08

Newark Electronics [newark.com, (800) 4-NEWARK]

150	06F6934	HSDL-4220 IR-LEDs	0.65

Mintron [mintron.com, (888) 383-9386]

8	MTV-360	B&W hi-res camera	179.00
8	MTL-0006	6mm miniature lens	12.00

Edmund Industrial Optics [edmundoptics.com, (800) 363-1992]

8	R40-601	4” lazy susan	2.95
2	K54-518	Kodak Wratten filter 87	46.45

```
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;; pupilSX.src
;;
;; assembly source code for Scenix SX 18-pin
;; microcontroller used to synchronize two LED
;; circuits to the field rate of a NTSC camera
;;
;; port A
;;  0 - [out] on-axis LED circuit
;;  1 - [out] off-axis LED circuit
;; port B
;;  7 - [in] Odd/Even square wave from LM1881
;;
;; Dave Koons
;; IBM Almaden Research Center
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

        device  pins18, pages1, banks1, oschs
        reset   start
        freq    4000000                 ;4 MHz

temp    equ     $08
        org     $00

start   mov     !ra,#$00        ;portA- all outputs
        mov     !rb,#$80        ;portB - pin 7 O/E input
        mov     !option,#$06    ;prescaler 1:128
        ;
loopA   jnb     rb.7,loopA      ;loop so long as O/E is low (hi->odd)
        mov     rtcc, #$76      ; load value for 1280usec delay
a1      jnb     rtcc.7,a1       ; loop s.l.a. bit 7 is 0
        setb    ra.0            ;turn on inner-LEDs
        mov     rtcc, #$0C      ; load value for 14848usec delay
a2      jnb     rtcc.7,a2       ; loop s.l.a. bit 7 is 0
        clrb    ra.0            ;turn off inner-LEDs
        ;
loopB   jb      rb.7,loopB      ;loop s.l.a. O/E is hi (lo->even)
        mov     rtcc, #$76      ; load value for 1280usec delay
b1      jnb     rtcc.7,b1       ; loop s.l.a. bit 7 is 0
        setb    ra.1            ;turn on outer-LEDs
        mov     rtcc, #$0C      ; load value for 14848usec delay
b2      jnb     rtcc.7,b2       ; loop s.l.a. bit 7 is 0
        clrb    ra.1            ;turn off outer-LEDs
        ;
        jmp     loopA
```