Hardware

The TinMan robot is based on a kit I found from a Chinese company named Robo- Soul. It is called the TK-6A Robot base with a 6-DOF Robot arm. The kit arrived in a timely fashion via post, but arrived with no instructions whatsoever. Also, the pictures on the website did not match the kit, either, so I have basically no guide to putting this thing together, other than trial and error. I will provide an abbreviated version here in the book that will get you through the rough parts. A complete version will be on the website for the book at http:// github.com/fgovers/ai_and_robots.

Beginning at the beginning – knolling

The best way to start with a kit this complex, particularly when you don't have instructions, is by knolling. What is knolling, you ask? **Knolling** is the process of laying out all of the parts in an orderly fashion, all at right angles, so that you can see what you are working with, as demonstrated in the following image:

Knolling was – discovered – by a janitor by the name of Andrew Kromelow, who worked at Frank Gehry's furniture factory. The factory designed and made chairs for Knoll, a company started by Florence Knoll, who designed furniture with simple geometric forms. Each night, Andrew would arrange all of the tools and workbenches incareful arrays of rectangular forms, which he called *knolling* in honor of the furniture. Weuse knolling to figure out just what we have and what order to put it together in.

Assembling the tracks

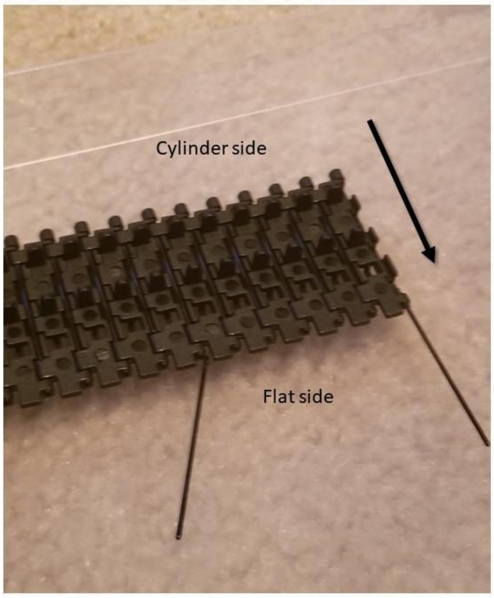
We start by assembling the track components. Grab the big triangular plates. The cut-out part goes in the back at the top, since that is where the motor and drive wheel goes. You will have one of two track configurations – one with either five small metal wheels, or, like me, a setup with four large plastic bogie wheels. I believe that the plasticwheels will be the default going forward. Each wheel goes into the smaller holes on the triangle piece – ignore the big holes. The wheels are held in place by the black hex boltswith bare shafts, and fastened with the nylon lock nuts provided. Leave the frontmost wheel off (or remove it later when we mount the tracks):

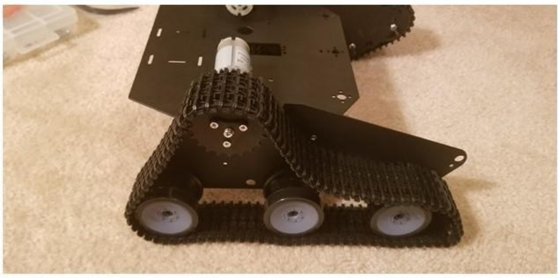
Next, we construct the drive wheels. Each drive wheel is made up of two sprocketwheels (with the rectangular teeth, a motor coupler (thick brass cylinder), three brass spacers (thin hexagonal hollow parts) and a triangular cap with four holes. Note that oneof the sprocket wheels has a round opening and one has a hexagonal opening. The brass motor coupler likewise has a hexagonal end and a round end. The motor coupler runs down the center of the drive wheel assembly. Attach the three brass spacers and the triangular end cap to the sprocket wheel with the hexagon opening using small round- head screws and lock washers. Put the motor coupler into the hexagonal hole and attach with a larger round head screw. Put the other sprocket wheel on the spacers and attach with small screws. Repeat for the other drive wheel. You will notice the small holes in the motor coupler for set screws to be added later – make sure you can get to these holes.There are sets of holes on either side of the motor coupler. I had to disassemble one of mydrive wheels to reposition the set- screw holes:

Attach the motor mounts (L-shaped bracket) to one of the robot base plates (largest plate with clipped corners) – both plates are identical. Use four longer screws and lock washers. Next, attach the motor to the motor mount using three screws. Now it gets exciting, as we can attach the two triangular track units at the side of the base plate to the upper pair of holes in the triangular drive plates, leaving the round corner for the motor to poke through. Attach the drive wheels to the motors by sliding the motor shaft into the coupler and attach with set screws (use the regular small round head screws).

Mounting the tracks

The most difficult part of the base assembly is getting the tracks onto the bogie wheels. First, you must assemble the tracks into continuous loops. The tracks are composed of a bunch of small plastic tread units that are connected to each other with small metal pins. If you look at your tracks, one end will have a pin, and the other will not. You have to remove the pin by pulling or pushing it out using a thumbtack (which was helpfully provided in the kit). You want to push the pin away from the side with the small cylinders – it needs to come out the other side. You can see this in the following image. Pull the pin out far enough to engage the two ends of the track, and carefully push it back in to connect the track. I did not need the extra track sections that were provided. Now we have a loop of track. If you put the frontmost bogie wheel on the drive section, remove it now. Loop the track around the bogie wheels and over the drive wheel. You will have to adjust the drive wheel in or out to engage the sprockets with the tracks. Now you have to lever the front drive bogie wheel into place by angling the long screw into its hole and tightening the nut until it all drops into place. This took a fair amount of effort and about an hour of careful wiggling to get it all to line up. You must keep at it until you can move the tracks easily around the bogie wheels and the drive wheel. If one of the bogie wheels is stuck, loosen up the lock nut just a tiny bit to allow it to turn without binding. There is no track tension adjustment on this kit, which can be a problem. You can make the front bogie wheel a slot rather than a hole to get some tension adjustment.I did not have to do this on my version of the robot kit:





Now we can assemble the other large base plate on the bottom two holes in the track plates and our drive base is complete. The second base plate goes upside down relative to the first plate – the bent outer section goes up. I staggered the two plates by rotating the bottom plate 180 degrees, but they can also go exactly parallel if you want. Iliked the staggered arrangement for later placement of sensors.

You will need to solder wires onto the drive motors before installing the robot arm. Some very nice *spaghetti* wire was included in the kit for this purpose.

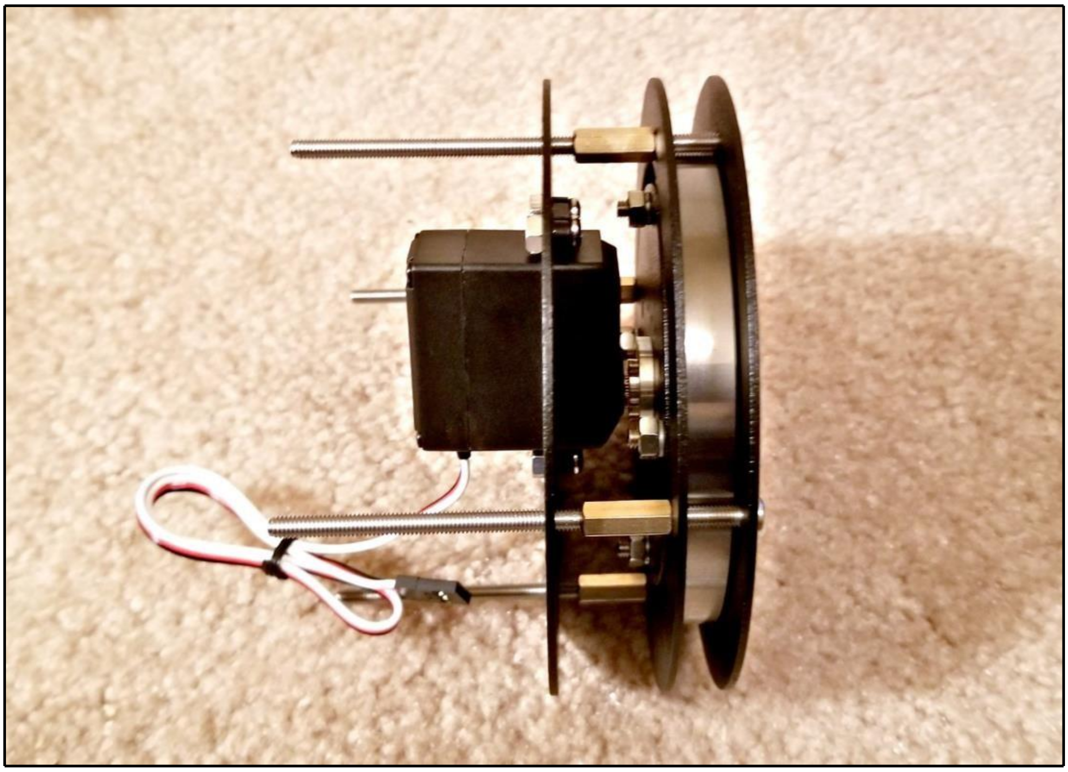
Now I have some good news and some bad news: We are done with the base (good news!) but we still have to do the arm, and it is much more difficult to assemble (bad news!).

An important note regarding Servo installation: you need to install the servos in the arm at the middle of their travel. Each servo can turn its gears through 170 degrees of angle. You need to assemble the arm with the servos in the middle. I ran the servos all the way to the left by turning the gear by hand, and then all the way to the right, andthen picked a point half-way before putting them into the arm. I tried to visualize each arm joint in the middle of its travel, and assemble the arm that way.

Arm base assembly (turntable)

The turntable is the rotating assembly that forms the base of the robot arm, and will create the robot shoulder rotate axis. This is a fairly involved part that I approached with a great deal of skepticism. However, we will see that the result is most satisfactory and appears to be a very solid design. We start with two critical steps. You must do the following first, or you will have to disassemble everything and start over. You can guess how I know this. First, pick one of the two smaller circular plates with the small holes in their center. Into one of these, you will attach one of the servo couplers, the aluminum disks that attach to the servos. To the other one you will bolt one of the "universal servo brackets", the U- shaped arm part that has two small arms and one large arm, along with a large number of holes. This will form the shoulder elevate joint later. You have to bolt these on first because you can't do it later:

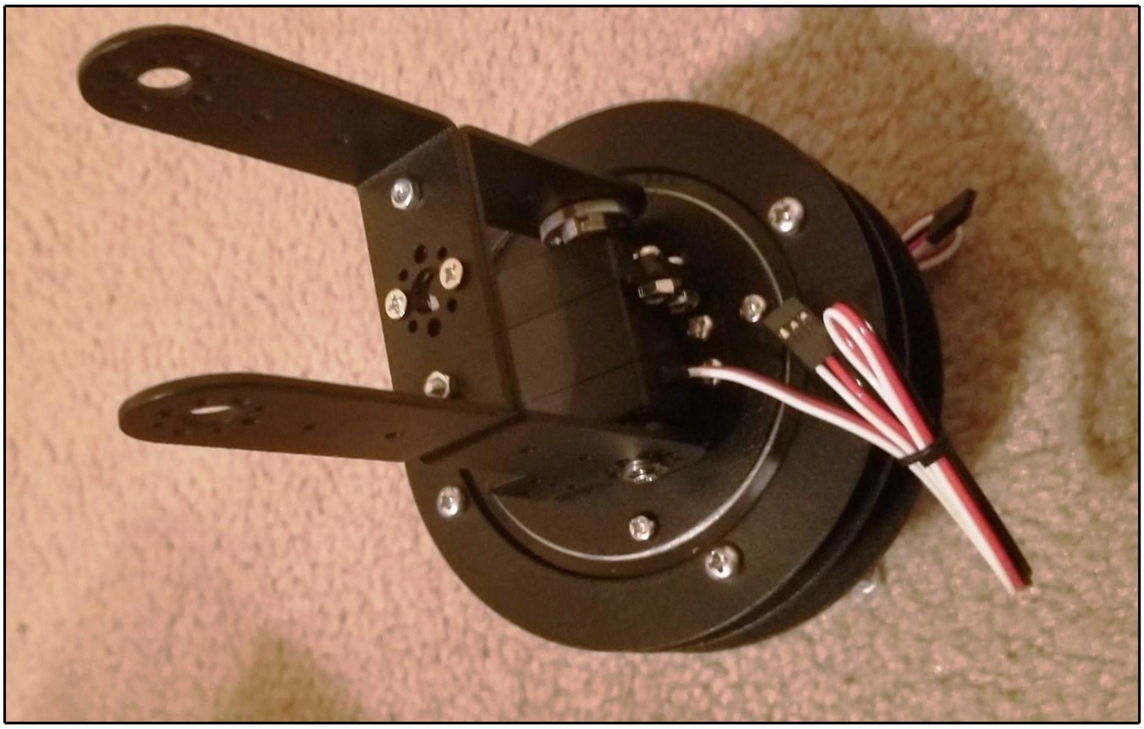
Now we sandwich the large bearing between the two small circular plates and attach them with four long screws and nuts. The servo attaches to the bottom (silver disk)and the arm servo bracket is on the top. The screws must go down so that we don't have anything poking up to interfere with the arm. After taking a moment to admire our work,we now attach to two larger circles with the big cutouts. These are secured with four of the very long screws. Next, we grab the large circle with the servo-shaped hole in the middle, and install one of our servos in that rectangular spot with four screws and nuts. Then, we need to secure the bottom of the larger turntable assembly by putting four of thebrass spacers all the way down on the very long screws until they touch the bottom of themetal plate. Now, mate the servo's spline output to the silver disk-shaped servo adapter you placed on the bottom of the turntable. We can now add four nuts to the long screws to secure the bottom plate. Be sure to get them all even and do not tilt the plate with the servo to one side or the other. Our turntable is done, and you can mount it to the robot mobile base if you wish, or keep the arm assembly all together and mount the turntable later after you have assembled the entire arm:



Arm assembly

The robot arm is made out of what is generally called the **servo construction kit** components. You will note that there are several standard parts used over and over. There is what I call the **universal servo bracket**, which is the U-shaped bracket with all of the holes. Most of the arm servos will fit into these brackets. There are three C-shaped brackets with rounded corners. We have one right angle bracket, one robot hand (which is pretty obvious), the five remaining servo motors, and a plastic bag with the servo couplers, which are aluminum disks with four holes around the outside and one hole in the middle. We also have three bearings in that same bag.

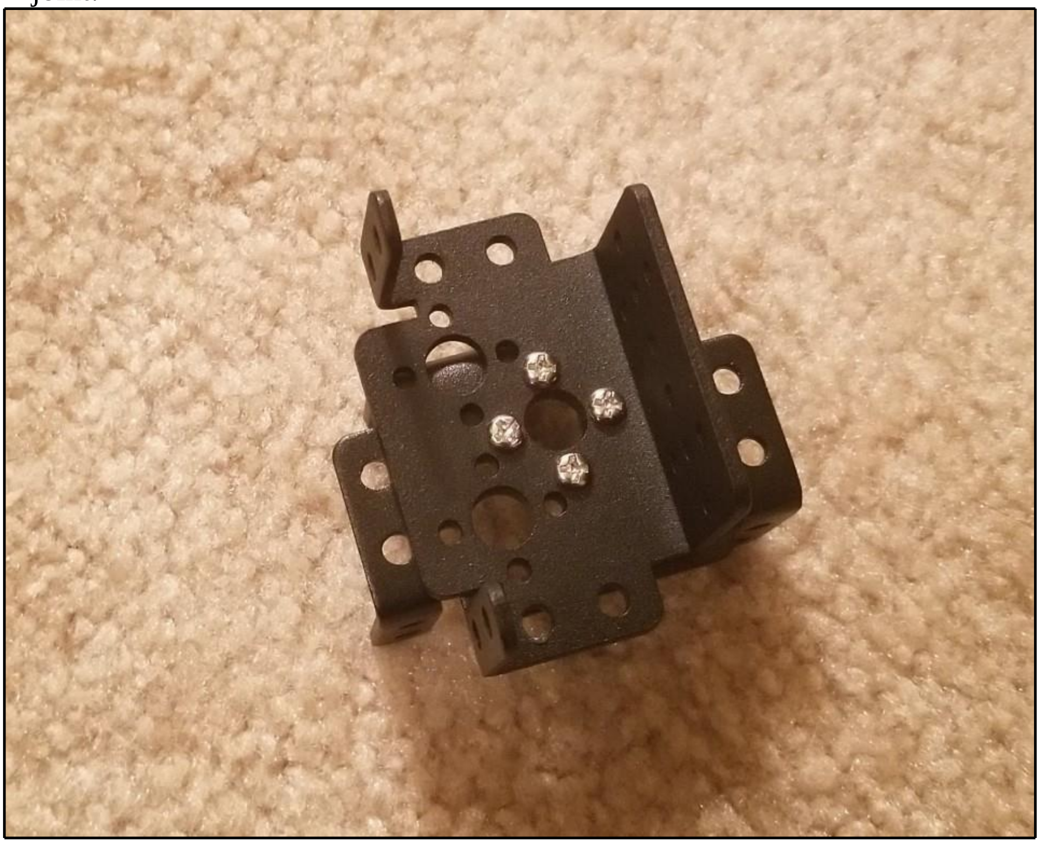
Our first step in the arm assembly is to take two of the large C brackets and fasten them back to back to make one long bracket with the curved sections on either end. I used four screws for this, but there are six holes. I picked the two outer and inner holes:



Now, all of the servos that attach to the C-shaped arms will go together the same way. We grab one of the small bearings and a short screw and fasten the bearing into theside of the rounded part of the C bracket away from the side of the servo. Now attach the bearing and the screw to the universal servo bracket (which I will just call a *US bracket* from now on) and fasten with a nut. If you think about how the servo goes in, you will see which side to attach the bracket. You now install the servo in the US bracket with four screws. Now, you have two pivot points on either side of the servo. Install the servocoupler (silver disk) to the servo and attach the servo coupler to the C bracket to completethe shoulder elevate joint.

Now for the elbow joint: we take one of the loose US brackets and also get the L-shaped bracket. We want to fasten these two together at right angles which is how the servo goes in. The image should explain how this works. Now, we repeat the technique we used to assemble the shoulder joint – we mount the bearing in the other end of the long C bracket, attach the universal bracket to it with a nut, and then install the servo. That completes the elbow, so now we work our way to the wrist. We attach the other C bracket to the end of the L bracket that we just attached to the elbow joint:

This next bit is a bit tricky. We need to fasten two of the US brackets together in the middle and at right angles to one another. We will be making a wrist joint that can both tilt and rotate, and that takes two servo motors perpendicular to each other. Once that is done, we can grab our remaining bearing and mount it in the C bracket that we attached to the elbow. Now use a screw and nut to attach one of the universal brackets tothe C bracket, just as we did before, and then install the servo and servo coupler to the wrist tilt joint:



This is as good a time as any to take a break and think through the next steps. Grab the robot hand, and you can directly attach one of your servos. Make sure you first put the servo in the middle, and then incorporate the hand grip into the middle of its travel aswell.

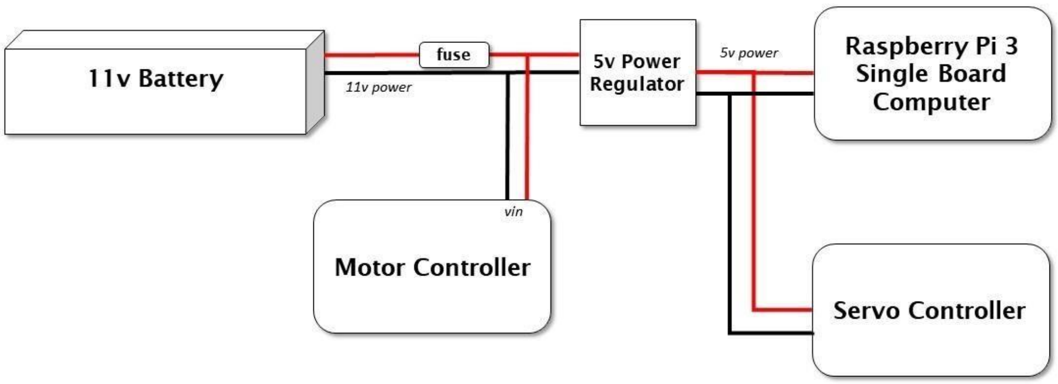
Then, line things up and install the servo. That was not too bad. Now install the wristrotate servo to the US bracket on top of the wrist joint. Our final assembly step should bepretty obvious. We put the servo coupler on the wrist with a screw in the center hole, thenline up the hand, and put two screws into the matching holes in the hand and the wrist.

Our erector-set construction is complete and we have the mechanical form of the robot.

Take some time now and tidy up all of the servo cables. There are four sets of servo extension cables in the kit, so attach these to the four top servos in the arm. I used cable ties to attach the cables to the side of the arm. There is also a spiral cable organizer – at least I think that is what it is called – in the kit. You can use this to also clean up the arm cables, and it makes everything all the same color.

Wiring

The power wiring diagram is included by way of illustration. We have four main electronic components: the Raspberry Pi 3, our robot's brain; the Arduino Mega; the motor shield; and the servo controller. We will be needing two sets of power – the Pi and servo controller need 5v, while the motor controller needs the full 11 volts from the battery pack. I purchased a 5v power supply to convert the battery to 11v. The motor controller needs power on the screw terminals labeled "EXT_PWR". Hence, we need to create a power harness with two splits – one split that puts 11v into the power supply board and the motor controller. We can then wire 5v from the power supply board to the Pi 3. A second 5v goes to the "servo power" connection on the servo controller board. This is thetwo-pin connector that is aligned with the six servo three-pin connectors, as can be seen in the following diagram:



The Pi 3 has sufficient power on its USB interface to power the Arduino (that has almost no load on it) and on the servo controller logic circuit, which also takes very little power. We run USB cables from Pi 3 to Arduino, and from Pi 3 to the servo controller. Later, we will plug a USB camera into the Pi 3 as well. If we need to, we can run a separate 5 v to the Arduino at a later date if we are having power problems. The USB lines also take care of control signals to the Arduino and the servo controller. The motorshield is plugged directly onto the top of the Arduino Mega and needs no further connections.

My plan of attack was to put together the battery and power converter and test themfor the proper voltages and polarity using a voltmeter before connecting any of the sensitive components. I also loaded the drivers and control software to the Arduino and Raspberry Pi 3 before plugging them into the battery power supply and connecting with USB cables.

All of the servo cables can be installed in the servo controller, being careful to put the black wires, which are the ground wires (or negative wires), all on the same side. They go to the outside of the servo controller. You will want to double check that all of the black wires on the servos are lined up on the "-" or negative pins.

I've provided connections for teleoperations using a PlayStation/Xbox-type joystick, which is useful for establishing that all motors are running the right way. We'll cover calibration in the software section. If one or other of the drive motors are running backward, you just have to switch the motor wires.