Build the BioCrab

By Michael Simpson

Figure 1

Last month I gave you some technical background into the AX-12 protocol as well as a simple 2 wheeled example bot. The AX-12 actuators used in this project are the future of robotics. With a fast and easy networked interface we no longer have to worry about the control aspects of our project. Now it's time to really dig into robotics. I'm going to show you how to build a large crab. I call this bot the BioCrab because I used a Bioloid Comprehensive Kit for most of his components. I like to think outside the box so you won't find this project in the BioLoid manual. The Comprehensive kit comes with its own controller but I'm not a big fan of closed system controllers or the graphical systems that most of them use. I also wanted to take advantage of the extensive library system of the DiosPro.

You can also build the BioCrab by purchasing a Frame Kit and 18, Ax-12's. This will yield you several more frame pieces as well as 18 extra #20 cables. The good folks over at CrustCrawler have several Bioloid options. They even carry the DiosPro and Dios Workboard Deluxe used in this project.

Assembly

Before I get into the assembly let me talk a little about paint. I wanted the color of my BioCrab to be black. For the bowl and PVC parts this was no problem. Simple plastic paint worked just fine. The Bioloid frame pieces were a different story. Robotis calls the material engineered plastic. I'm not sure what that means but they are almost impossible to color. I tried various paints and dyes but had little luck; the paint would just fall off and the dye just didn't affect the color. What did work however was a permanent marker.

I used both a fine and ultra fine point marker to color some of the pieces. If you do decide to use paint, the markers are great for touch up. The F10 piece shown in Figure 2 is probably the worst case scenario because of all the tiny crevices.

It's not necessary to cover every little crevice; much of the piece may not be seen once assembled. This is one reason that I recommend full assembly before painting. Once you have the BioCrab assembled you can remove the pieces you want to paint or color.

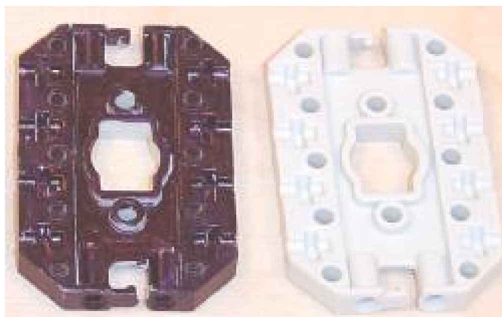

Figure 2

Assemble the 6 Legs

The BioCrab is a very easy robot to build. First you will need to assemble 6 legs. I recommend assembling a single leg, then once you have it down it's a simple matter of duplicating the remaining 5 legs.

In the steps that follow I will be referring to Figure 3. The frame pieces are marked F1 through F7 and the AX-12's are marked ID1-ID3. AX-12's have a small index located on the hub. There is also an index mark on the AX-12 body as well. These should be aligned before assembly. I recommend you download the AX-12 manual as it gives detailed instructions on how to attach it to the various frame pieces.

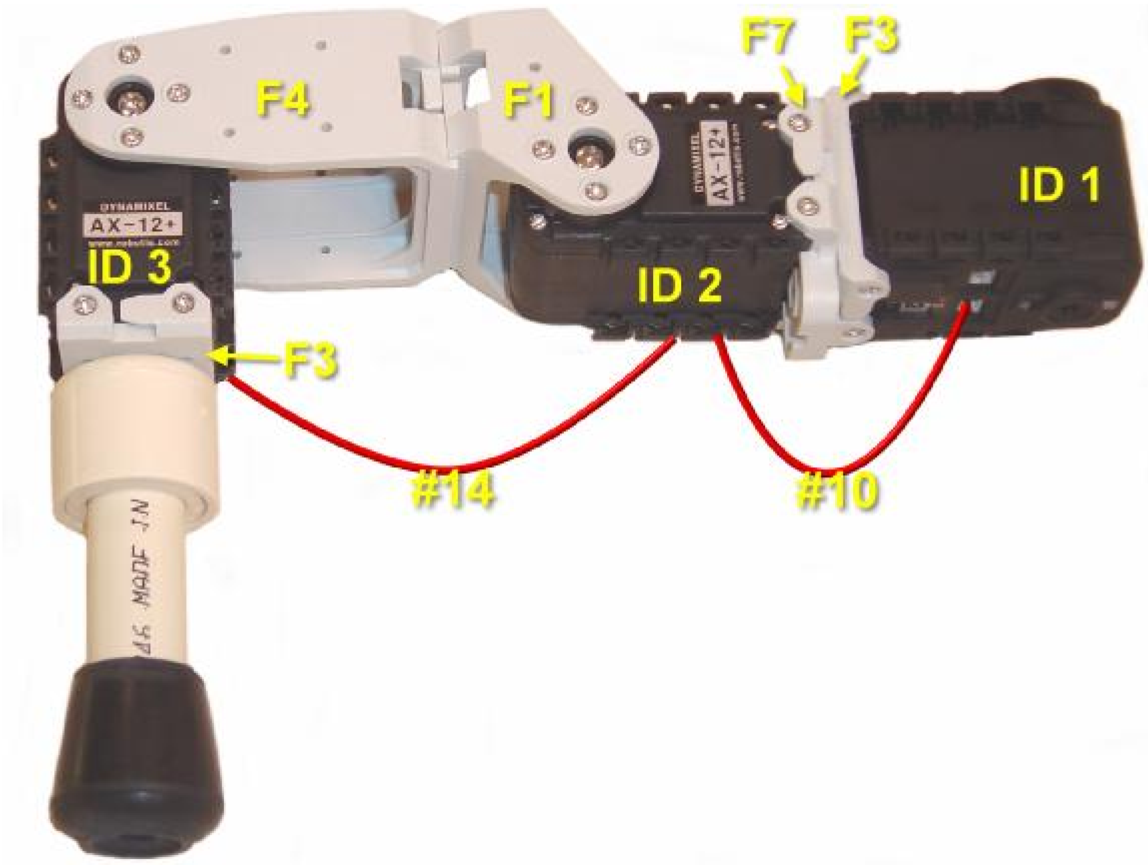

Figure 3

Step 1

Using four S1 screws and nuts, attach an F3 to a F7 as shown. Note that the F7 has a rounded lip. This lip should be facing down.

Step 2

Using four S1 screws and nuts, attach an F1 to an F4 as shown. One side of the F4 has a lip. This lip should be facing up.

Step 3

Attach an F3 to a 3/4" PVC cap as shown. To do this, center the F3 on the top of the cap and mark two of the apposing holes with a fine point marker. Drill out the two holes with a 5/64" drill bit. Use two S2 screws and nuts to attach the pieces. This is done by inserting the screws through the two holes from the inside of the cap. The nuts are placed in the F3. Make the connections very tight because you won't be able to do so later.

Step 4

Insert a 2-1/2” 1/2” PVC pipe into a 3/4" x 1/2" PVC bushing as shown. Tap it in place so it bottoms out.

Step 5

Insert a 3/4" x 1/2” bushing into the cap as shown.

Step 6

Insert a rubber foot over the other end of the PVC pipe as shown. I picked up the feet I used from my local home center. There were many options. Many department stores also sell these feet as well. Take one of the legs with you so that you can make sure you have a tight fit.

Step 7

Attach the completed Foot to an AX-12 with an ID of 3. Make sure the orientation is as shown with the hub facing up. You will need a bushing (BU) and a washer (WA) inserted into the F4 hole opposite of the hub. Insert an SB screw into the bushing and 4, S1 screws into the hub as shown.

Step 8

Attach an AX-12 with an ID of 1 to the F3/F7 assembly as shown. This is done by inserting 4 nuts into the slots on the bottom of the AX-12 as shown in the AX-12 manual. Slip the F3 over the mounts as shown and insert four S1 screws into those nuts.

Step 9

Attach the F7 side of the F3/F7 assembly to an AX-12 with an ID of 2 as shown. Don’t forget to insert the 4 nuts into the slots on the bottom of the AX-12.

Step 10

Attach the other end of the AX-12 (ID 2) to the F1 as shown. Again, the Hub is facing up and the bushings are on the bottom. Attach with S1 and SB screws as before.

Step 11

Repeat steps 1 – 10 for each of the remaining 5 legs. The legs should have the AX-12, ID’s as shown.

Leg 0 = ID 1,2,3
Leg 1 = ID 4,5,6

Leg 2 = ID 7,8,9
Leg 3 = ID 10,11,12
Leg 4 = ID 13,14,15
Leg 5 = ID 16,17,18

I will refer to the leg numbers later when we attach them to the Base.

Step 12

Attach a #14 cable between the AX-12 on the foot and the middle AX-12 as shown.

Step 13

Attach a #10 cable between the middle AX-12 and the hip AX-12 as shown. Note that the comprehensive kit only comes with four #10 cables. To create a cable for the remaining two legs attach two #6 cables with a 3-pin header.

Assemble the Base

The BioCrab base is even easier to assemble than the legs. Start with a bowl that is at least 6” in diameter. When choosing the bowl there are a few things to consider:

1. The bowl should have sides that are straight. If the sides are angled it will affect the geometry of the legs.
2. The material should be as riged as possible. If you purchase a thin plastic or vinyl bowl the robot may flex and wobble when it walks.
3. The bowl should be between 6” and 8” in diameter.

The bowl shown in Figure 4 is a Stain Shield made by Rubbermaid. The bowl is clear but it can be painted. If you decide to paint your bowl, paint both the inside and outside of the bowl.

Figure 4

Step 1

You need to mark 6 equal points on the bowl. The easiest way to do this is to use a clock face as a guide. Place the bowl gently on the top of the face and using a marker make a mark at the 12, 2, 4, 6, 8 and 10 hour positions.

Step 2

Place an F2 frame piece on your mark. Using an ultra fine point marker mark 4 of the holes. Do this for all of the clock marks that you made in Step 2. It's not important where you place the F2 piece on the clock mark. What's more important is that you are consistent. In other words if you center the F2 on the clock mark it's important that you do the same on all the other marks.

Step 3

At this point you can paint the bowl and F2 pieces.

Step 4

Using four S1 screws and nuts attach each F2 frame piece to the bowl as shown in Figure 4.

Step 5

It’s time to attach the CM5 to the base. The easiest way is to sit the CM5 on the top of the base and to place a thin Philips screwdriver in the 4 mounting holes to score the marks.

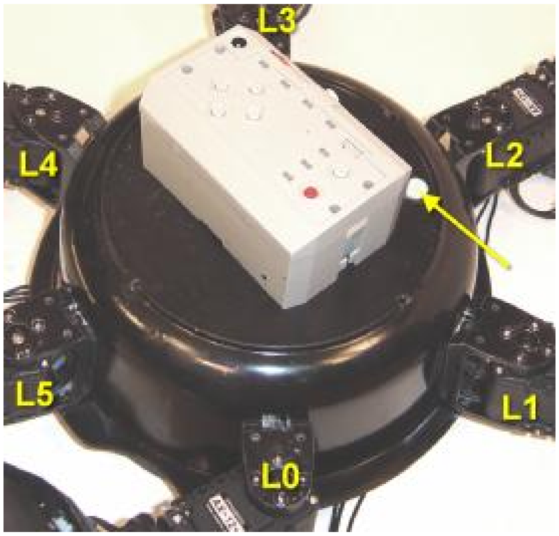

Figure 5

Notice the orientation. The CM5 should be roughly in-line with legs1 and leg4 as shown in Figure 5. Also notice the small hole drilled in the top of the base. We will use this later to pass one of the AX-12 cables to our Dios Workboard. I drilled a 1/2” hole for mine but you can use a rotary tool to create a smaller hole that is just large enough to pass the cable.

Once the 4 CM5 holes are scored drill them out with 5/64 drill bit.

Step 6

Attach the CM5 from the under side of the base as shown in Figure 6. Use four S2 screws and nuts.

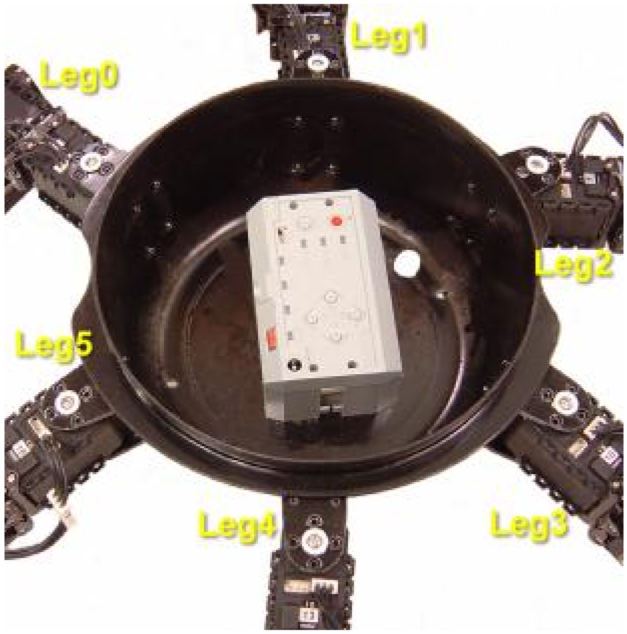

Figure 6

The power connector should be on the end closest to leg 4 as shown in Figure 6.

Step 7

Attach the Dios Workboard Deluxe to the base as shown in Figure 7. The board should be located so that the hole is to the left of the board as shown. To mark the board place the board on the top of the base and mark or score the location of the four holes. The bowl I used had a small 1/8" lip right where the screws attach the board. I used a small rotary tool to grind away a small portion of the lip where the holes were located.

First attach four 5/8" standoffs to the base with four 3/8" #4 machine screws. Place a #4 washer on the screws, then pass the screws through the holes from the under side of the base. Leave the standoffs loose.

Next, attach the board to the standoffs with four 1/4" #4 machine screws. Tighten all screws at this point.

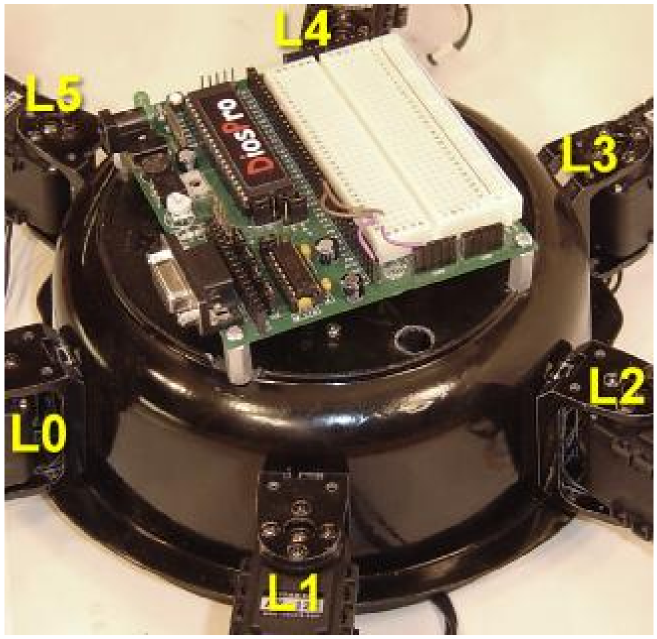

Figure 7

Step 8

Attach a #18 cable to each of the CM5 ends as shown in Figure 8. These then connect to leg1 and leg4 as shown. Attach the Expansion PCB to the CM5 with a #6 cable as shown.

Attach a #20 cable from the Expansion PCB to each of the remaining legs as shown in Figure 8. The last #20 cable connects to the remaining connector on the Expansion PCB and through the hole as shown.

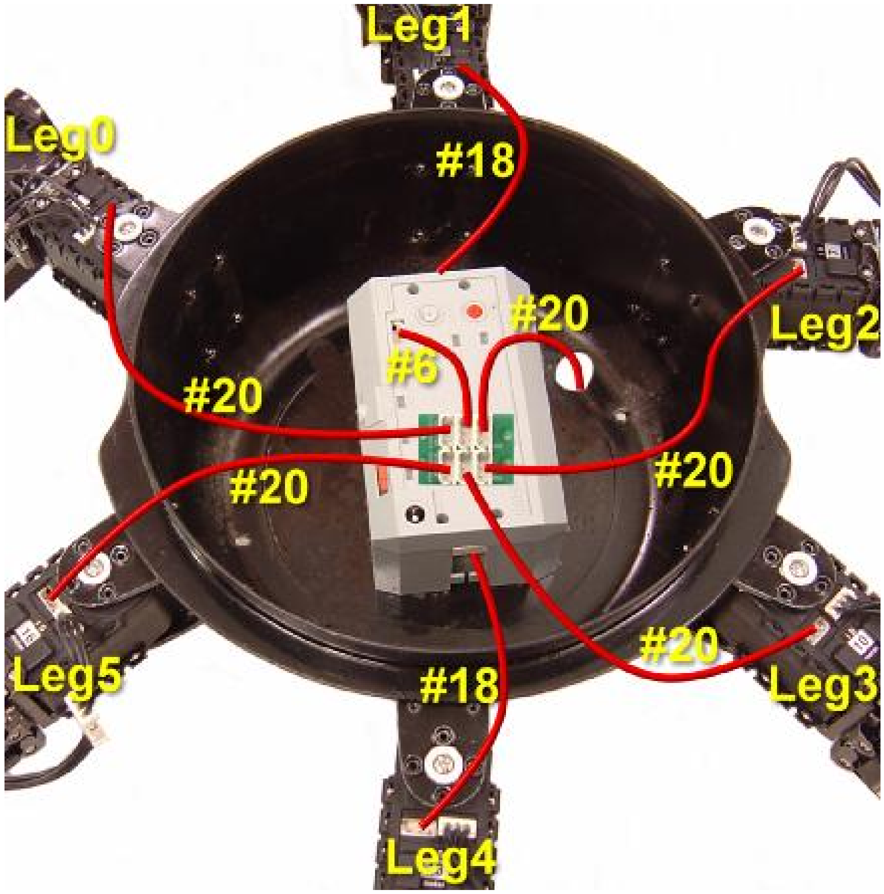

Figure 8

Step 9

Connect a 3-pin header to the end of the cable that is protruding from the hole. The connector has a flat side and a rounded side. Take the rounded side as shown in Figure 9 and mark the GND lead with a small black mark.

Figure 9

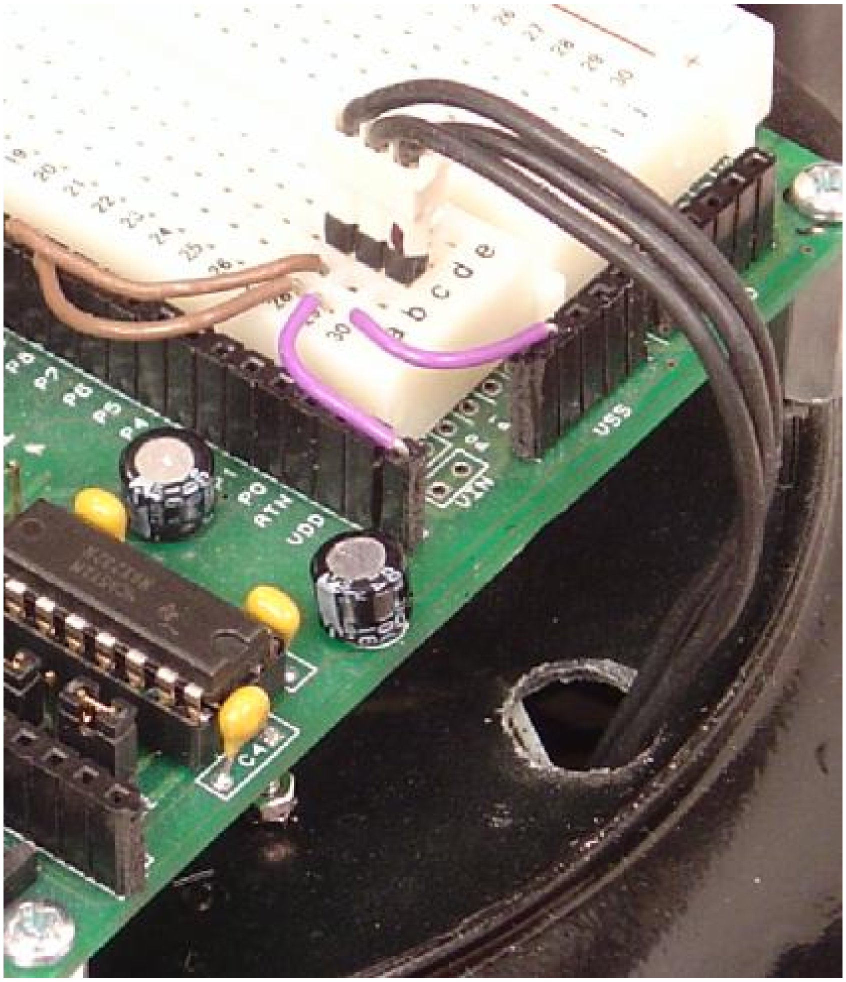

Figure 10

Wire ports 8 and 9 on the breadboard hole 28 as shown in Figure 10. Connect the Vin lead to hole 29 on the breadboard. Connect VSS to hole 30 as shown.

Step 10

The final step is to connect the cable with the header to the breadboard as shown in Figure 10. I recommend that you remove both the DiosPro chip and the RS232 chips from their sockets. Once the cable is connected switch on the CM5. The CM5 LED's should light up. The green LED on the Dios Workboard should also light up.

Now switch off the CM5 and plug the two chips into their sockets. Once you power on the CM5 the LED's should again light up.

BioCrab Software

Test Software

You now have a complete BioCrab. Its time to start the legs moving. Just to make sure everything is connected properly let's run some test programs. Before you run any of the programs you should build some sort of stand for your BioCrab. The stand support should be tall enough to keep the legs from touching the surface on which it is sitting when fully extended. A 1 gallon paint can works well for this.

Connect a serial cable from your PC to the DiosPro. Power up the DiosPro and AX-12 network. Load the first program called **TestHHip.txt**. This program will test all the horizontal hip joints in succession. The horizontal hip is the AX-12 that is connected to the base.

Click the program button and the program will compile and upload the test program. Verify that all the joints are moving in sequence.

Load the **TestVHip.txt** and the **TestKnee.txt** programs and test those joints as well. If one or more of the joints don't move there could be several reasons why this happens. Power down the BioCrab and make sure the legs can move freely without sticking. It's also possible that the AX-12 ID needs to be changed. There are a couple of ways you can change the ID. You can use the CM5 and Bioloid software to change the ID. I have also created software that will allow you to communicate with the AX-12's from your PC. One of these programs will allow you to change the IDs of the devices. These programs can be downloaded from the Kronos Robotics web site.

WalkerAX Library

In order to move the 18 AX-12 devices in a synchronized manor I have added a new series of commands to the DiosPro AX library that allows you to synchronize the movement of several AX-12's.

There are three commands:

AXclearsync
Clears the sync memory and prepares for a new sequence of synchronized commands.

AXaddsync
Lets you add a goal position and speed to a device.

AXsendsync
The AX-12 devices will not begin moving until this command is sent.

These commands use one of the free memory banks of the DiosPro so you can send sync commands for up to 50 devices at once.

Here is an example of moving 4 devices with these commands.

```
AXclearsync
   AXaddsync 1,500,100
   AXaddsync 2,250,1000
   AXaddsync 3,350,400
   AXaddsync 4,500,100
AXsendsync
```

Back when I built the FaceWalker robot I used a library called IK that used Inverse Kinetics to calculate the position of the legs. This program worked fairly well but had many issues. First, it relied on many trigonometry calculations. These worked fine but left little processing power left to do other functions. They were complicated and very difficult to modify. This made it almost impossible to use with other walkers. I decided to write a set of state driven routines that would give me the same functionality. That is how the WalkerAX library was born. The WalkerAX library is included with the Dios compiler. To use the library just add the following include statement to the end of your program.

include \lib\WalkerAX.lib

The WalkerAX routines were designed on the premise that three legs are always in contact with the ground. The other three legs are moving into position so that they may be lowered. Once one set is lowered the other set is raised. For the sake of this discussion legs 0, 2, and 4 are triangle A and legs 1, 3, and 5 are triangle B.

The main walker state machine has 4 states. Let's take a close look at what happens in each of those states. Servo Magazine has a download called **BCslowspin.mpg**. I used program BioCrabspin.txt as a quick gait demonstration. I set the speed at the lowest setting and added a 1 second delay between states. It should help to demonstrate the following state descriptions. In Figures 11 through 14 the red legs indicate legs that are on the surface supporting the BioCrab. The other legs are up and moving to the idle position.

State 1

In this state we force triangle A (legs 0, 2, 4) down. Legs 1, 3 and 5 should already be down as shown in Figure 11. The triangle down routines take into account the global variable called **height** to allow you to change the walking height of the BioCrab on the fly.

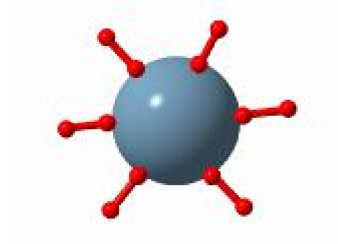

Figure 11

Note that when the walker is initialized all legs are set to the down state at a height of 150. The second time through, the B legs will have been in their moved position.

State 2

Here we move the triangle B (legs 1, 3, 5) up. The amount of lift from the down position is set by the global variable called **leglift**. Also, at the same time we are moving these legs up I am returning them to their center (idle position) as shown in Figure 12.

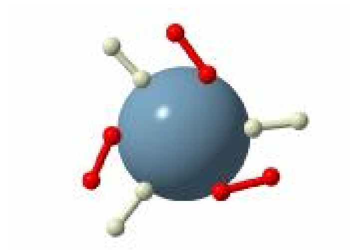

Figure 12

This is a busy state because I calculate the movement of each of the triangle A legs. Several variables are looked at here that I will go into later. This leg movement is what actually moves the BioCrab.

State 3

Remember that we were repositioning the B triangle so we know that once we get to this state we simply only need to move them down. This is the B version of State 1. At this point all legs are once again in the down position as shown in Figure 13.

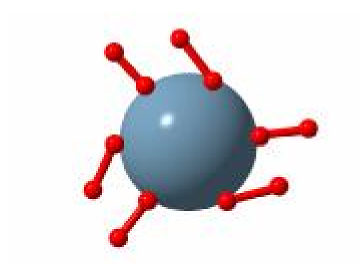

Figure 13

State 4

This is a mirror image of State 2. We move the A triangle up and set the now down B triangle into motion as shown in Figure 14. We then cycle back to State 1 and the whole thing starts once again.

Figure 14

Although it is hard to show, these states are not finite. For instance, the state only initiates the movement of the legs. There is a calculated delay in-between each state in which the legs are moving. I have played with a 6 state gait. It is a little less smooth but can handle a rougher terrain. In a 6 state gate we add the additional states 2 and 4 into two parts. Before sending the B or A legs to their idle state we first move them up.

The real calculations are done in **moveleg** function. The **moveleg** function calculates the position it needs to move based on the following global variables.

State

The current state the State Machine is in.

spin

The amount of momentum clockwise or counterclockwise the BioCrab is performing. The range is in 100 – 500 with 300 indicating no momentum.

fwd

The amount of momentum forward or backward the BioCrab is performing. The range is in 100 – 500 with 300 indicating no momentum.

strafe

The amount of momentum side to side the BioCrab is performing. The range is in 100 – 500 with 300 indicating no momentum.

height

The walking height of the BioCrab. This has the range of 0-200.

speed

The walking speed with a range of 1-5.

leglift

This is the amount the leg is lifted off the surface. It has a range of 0-200.

Once the new position is calculated we can calculate the actual amount of movement. This is needed so that we can set the speed of the AX-12 we are moving. For the most part we want all the legs put into motion to complete their range of movement at the same time. The AX-12's ability to set the speed is what allows this function. The BioCrab walks much smoother with this ability.

Walker Example

The program BioCrabDios.txt is a walker program. It will cause the BioCrab to walk forward at the slowest speed, and then walk backwards. The BiCrab will then spin at speed 3 then start the cycle again.

Take a look at the code and you will notice that I created a variable called **statecounter** that increments each time the main state machine handler **walkerAX()** is called. This is used to determine how long the BioCrab does a particular movement. Notice that we make a call to the routine called **initwalkerAX().** This is needed to set some of the default variable states as well as initialize the AX network library.

My Old Favorite

And yes. I have once again included a small controller program that uses an IR remote to control your BioCrab. The program is called **BioCrabIR.txt** and while it does not give you total control over your little friend it will allow you to put it through its paces.

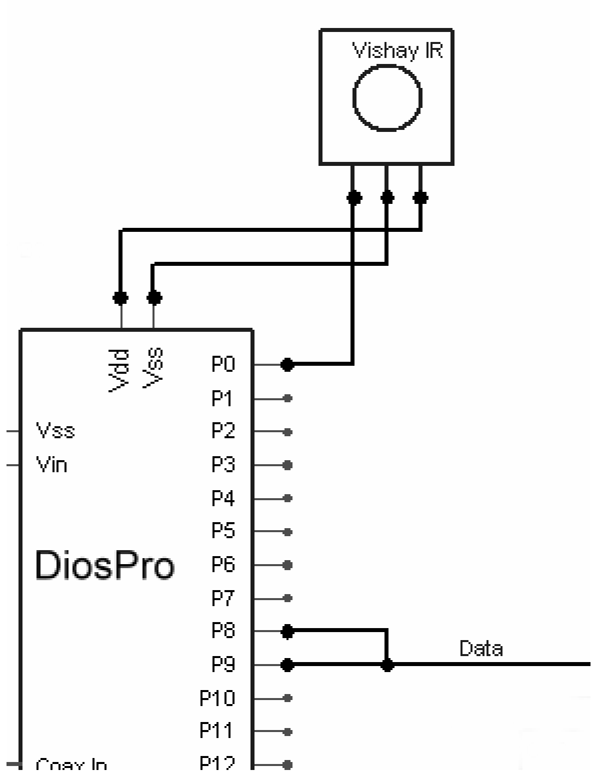

Figure 15

Figure 15 shows how to connect the Vishay IR module. Use any Sony remote to control the BioCrab.

VOL = Spin
CH+- = Fwd/Rev
Reverse/Forward = Strafe

Going Further

Are the WalkerAX routines perfect? No. I plan on doing a lot of tweaking. One thing I can see is instead of moving the legs back to the idle center position I could set them up for a better stride.

Also I don't test for any AX-12's that may have been shut down. There is plenty of processing time left to do this as well as other function. The program spends much of its time waiting in delay routines. One option I plan on providing is the ability to turn off all these delays so that you can do the delay yourself. This in turn will allow you to place AX-12 monitor routines in your main loop. You could then watch for too much load or lack of position update. This would indicate that one of the legs has come in contact with an object.

Feel free to play with the example program or add some sensors. There are plenty of sonar and various other interfaces on the Kronos Robotics web site. The AX network library also has support for the AX-S1 sensor.

We used the CM5 for power distribution. Feel free to replace it with your own battery pack and cable harness. If you decide to do this, I recommend wiring in a main power switch.

What's Next?

I mounted the Dios Workboard on the top of the base in order to do various experiments. One such experiment is a very cool remote control system I plan on interfacing in the next article.

Eventually I will move the Dios Workboard to the inside of the base so that I can add some sort of graphical display to the top. I'm thinking of a giant animated mouth.

All the example programs as well as the source are available for download at:
http://www.kronosrobotics.com/Projects/biocrab.shtml

Parts

Available from CrustCrawler – www.crustcrawler.com

- 18, AX-12 Smart Servos
- Biolod Frame Set
- CM5 or equivalent (Used for power distribution)

Available from Kronos Robotics - www.kronosrobotics.com

- DiosPro Chip #16148 (Also available from CrustCrawler)
- Dios Workboard Deluxe #16452 (Also available from CrustCrawler)
- DiosCompiler Free Download from www.kronosrobotics.com
- Vishay IR module #16226

Misc

- Eight 3/8" #4 machine screws, Jameco #40969
- Four #4 washers, Jameco #106826

- Four #4 Standoffs, Jameco #77519
- Plastic Bowl. (See Text, Wall Mart or Target)
- Six 1/2" x 2-1/2” PVC pipe.
- Six 3/4” PVC caps
- Six 3/4" x 1/2” PVC bushing. This is an adapter to so that you can insert the 1/2” PVC pipe into the 3/4" cap.
- Six 1/2" rubber feet. These need to fit tightly over the 1/2" PVC pipe.
- 9-Pin Serial cable available from various sources. Needed to program the DiosPro.

The PCV and rubber feet can be purchased at most hardware stores or Home Centers.

Jameco Electronics can be found at www.jameco.com