Then and NOW

SERVOS

by Tom Carroll

Servos? Just what is a servo (or a servo motor or servo mechanism, as they are sometimes called)? Is that a year's collection of this magazine? Most of us who have built robots have used one or more of these in our creations, but not all robots use servos. Most of the larger varieties of robots don't use servos though they might employ shaft encoders to provide some sort of positional feedback to a controlling microcontroller or computer. Most combat robots (like the ones that seem out of control) don't use any form of them, so why do so many experimenters utilize them?

Who would have ever thought that these small plastic boxes would have had such an impact on experimental robotics? I remember playing with a four channel R/C system years ago, trying to figure out how I could use it in a robot. Most of my robots were usually rather large and the tiny servos could do little more than move small 'special effects' appendages. Cute 'decorations' really served no useful function, so I decided to hack one to see what I could do with it.

I believe that first thing I made was a linear actuator. Pulling the 4.7K pot out, cutting off the stops from the output gear, I attached a 25 turn lead screw and a 25 turn 5K trim pot (in the place of the other one) to the output shaft and had an amazingly powerful push-pull actuator. Other experimenters in our robotics group were attaching them to arm and leg joints, and driving the servos with 555/556 timer circuits or 6502 microprocessors, and a few started to use them as drive motors for small robot's wheels.

Typical Servos Used in Robotics

The three servos shown in Figures 1a, 1b, and 1c are just a tiny fraction of the many types, torque capacities, sizes, and weights available from the many manufacturers today. Servos are quite often the only motive force of many experimenter's robots. Most of the beginner's kits from Parallax and others use similar servos in small robots.

Tabletop robots can make use of the little motor/gearbox to drive a set of wheels and the associated electronics to receive the pulse trains from a microcontroller and convert them to drive signals. This is a cheap and effective way to get a robot design from a few sketches to a working machine in a few hours.

As robot experimenters, we think of those little black boxes that were originally developed for model airplanes as the only 'servo' that we're familiar with. Many of us have boxes of them; some hacked, some in pieces, and some actually in one piece.

Servo Feedback

With the advent of specialized ICs and electronics, modern servos have emerged as marvels of mechanics and electronics. Servos have been used in industrial applications for years, long

FIGURE 1a. JR servo.

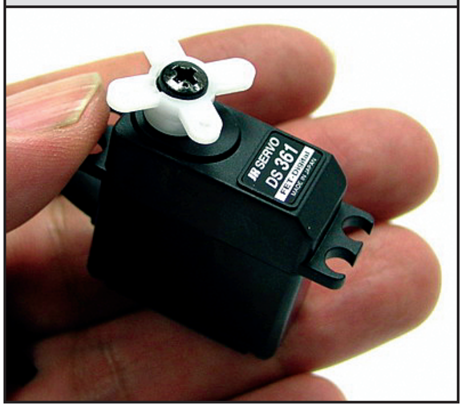

FIGURE 1b. HiTec robot servo.

FIGURE 1c. Futaba coreless servo.

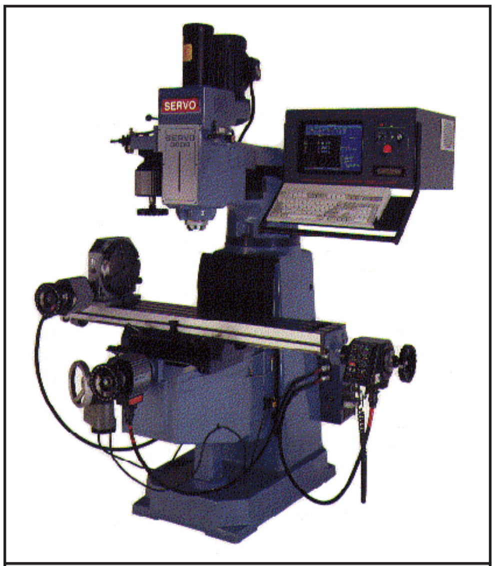

FIGURE 2. Three axis milling machine set up by Servo Products.

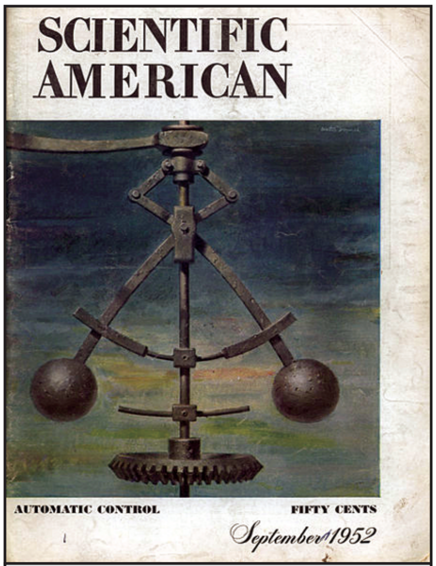

FIGURE 3. Flyball governor on the cover of *Scientific American*.

before model aircraft found them useful to move various surfaces to change the direction of flight. Newer applications are popular for CNC machine tool use.

Figure 2 shows three servos used to move the three axes of a milling machine by Servo Products. Way back in 1787, James Watt used a servo-like device — the flyball governor — to regulate the speed of his steam engines. Figure 3 from the cover of a 1952 *Scientific American Magazine* shows a classic drawing of the flyball governor. It certainly was not what we think of today as an electrical/electronic servo, but it could be set in different positions to control the speed of a steam engine.

The revolving set of balls was directly connected to the engine's output shaft and as the speed increased, centrifugal force caused the balls to move outward, pulling down the upper ring and connected lever. As this ring moved downward, it would slowly shut down the flow of steam by moving a valve, thus slowing the engine and revolving balls.

At one point, a stable speed was developed. By manually changing the distance between the ring and where the valve cut down the steam flow, one could set the engine's speed wherever desired. A relief valve was set to open at a specific pressure, thus preventing an exploding boiler.

No, this certainly is not a typical servo that we're familiar with, but it did utilize feedback to control a machine. No 1.0 to 2.0 millisecond pulses were sent remotely to Watt's engine to control speed, just a simple mechanical adjustment by a human operator.

What is a Servo?

Just like the definition of a robot is so different to so many people, a servo has many definitions. Allow me to present four definitions of the term servo that I found at random through Google:

A servo is: *"An electromechanical device that uses feedback to provide precise starts and stops for such functions as the motors on a tape drive or the moving of an access arm on a disk (PC Magazine)."*

A servo is: *"An automatic device used to correct errors in the operation of machinery, used in satellite-tracking systems, power-steering systems on some cars, and to control robots and keep ships on course (encyclopedia)."*

A servo is: *"A small mechanism inside the RC vehicle, the servo is a device with a motor, gears, and circuits that controls things like steering and speed. A typical RC car has a steering servo to make the wheels turn and a speed control or throttle servo to make it go faster or slower. Other types of servos may be present to control other functions (radio-control car enthusiast's definition)."*

A servo is: *"An electro-mechanical device that is used to convert the received signal into mechanical movement. Servos are used to move control surfaces, throttles, retractable landing gear, or auxiliary functions (model airplane enthusiast's definition)."*

Servo is: *"The name of a great robot experimenter's magazine." (Sorry, I just had to put that in.) If you Google 'servo,' you'll find most definitions and hits are about the model airplane types.*

How Does a Servo Work?

Are you really any closer to knowing just what a servo is? So many articles in this magazine (including some of mine) have gone over how a typical model aircraft servo works. The more popular and certainly cheaper models utilize a pulse width modulation pulse train from the R/C receiver.

The pulse train consists of 50 to 60 pulses per second with each pulse being one to two milliseconds long, though experimenters have used 0.8 to 2.2 ms pulses to drive the servo further than the typical 90 to 120 degrees of travel. A shorter series of pulses will drive the servo's output shaft one direction, and the longer pulses will drive the other way — with positions in between for pulses closer to 1.5 ms.

In these older servos that have been used for years, there are three wires to the servo: a signal wire (for the pulse train) that can be a number of colors; a 4.8 to 6 volt power wire that is usually red; and a ground wire that is usually black or brown. Note that there is no output wire to inform an operator or microcontroller just where the servo's shaft is positioned.

Early Model Aircraft Servos

One of the first R/C systems that I used was by Kraft. Figure 4 shows an earlier analog Kraft system with three servos mounted in the airplane, lying behind the transmitter and receiver in the foreground. Back in the '80s, several of us from the Robotics Society of Southern California were invited down to the Kraft

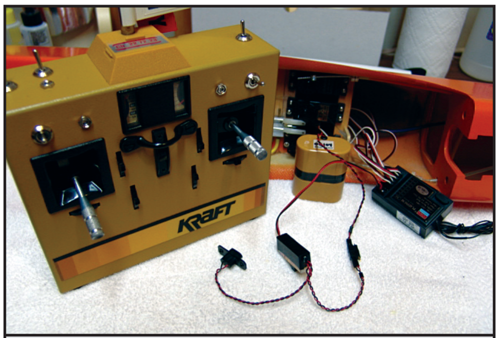

FIGURE 4. Early Kraft radio.

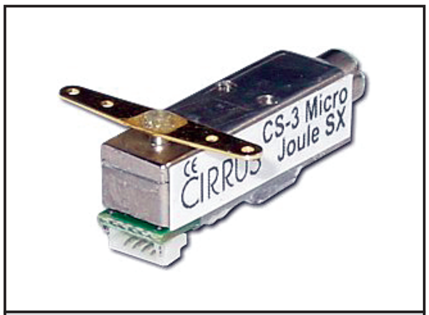

FIGURE 5. Cirrus CS-3 Micro Joule SX servo.

plant in Vista, CA and were given a tour of the facility. The guy leading us around the Kraft facility gave us a lot of servos, receivers, and battery packs just for good will; maybe he saw that the end was near. Futaba from Japan was starting to really hurt the US manufacturers and Kraft's days seemed numbered.

Experimenting with them at home, I found the Kraft servos to be quite well made. I also had an old Heathkit R/C system that I built that used two PS-4 servos made by Orbit (remember kits?). Kraft later came out with the smaller KPS-12 servos that some people I knew built into robot joints for walkers. I later began to frequent the Hobby Shack (now Hobby People) in Fountain Valley, CA and found that Futaba and HS' Cirrus line of R/C equipment to be a lot cheaper for my R/C projects.

One of my first R/C robots for a movie used a Hobby Shack AeroSport four channel system with two Vantec speed controllers for the two wheels and two very large Cirrus servos for the two arms. I used coil springs to compensate for the arm's weight and the little robot could easily pick up over a pound.

Futaba took the lead several decades ago and is still one of the more popular R/C systems with a full line of servos for all applications, including servos designed specifically for robots. HiTec of Korea also has a line of servos specifically designed for robots, as does the Robotis Bioloid line of Dynamixel servos (actuators), also from Korea.

Servo Selection

You may be wondering just what type of servo that you'll need for your project. For economy's sake, you can start with the cheaper analog servos with a three pole cored motor, plastic gears, and bushings for the shaft. These will work great for almost all applications where you need to study the basics before advancing to your final design.

The next step for tougher applications is to buy a metal geared servo with ball bearings on the main shaft. Coreless motors have quicker changes in speed over the three and five pole cored motors. The most advanced are the digital servos with an embedded microcontroller to deliver a greater number of PWM pulses to the motor for quicker response, greater accuracy, and torque with less deadband. They do draw a bit more power to operate, but that is usually not too much of a concern for robot builders.

Of course, servos vary widely in their torque, weight, and size. The Cirrus CS-3 Micro Joule SX servo weighs only three grams (its four channel receiver weighs a bit less), yet it only has seven oz. in. of torque (see Figure 5). Monster servos can weigh over a pound and put out 10 foot pounds of torque or more. It all depends on what you need.

This single paragraph certainly cannot narrow down the right servo for your application; you need to go to the Internet or to manufacturer's websites and do some research.

Servo Feedback vs. Feedback to a Microcontroller

This magazine takes its name from these devices that so many of us have used in our robots for years, yet servos offer no built-in intelligence. They only take commands from a microcontroller or R/C receiver and move to a certain point and stop. But hack the little suckers and you have an intelligent drive motor of sorts.

After reading my August column on Robot Arms, Alex Dirks of CrustCrawler wrote *SERVO* concerning what he felt were incorrect statements that I made concerning servos used in many experimenter's robots — the types used with radio controlled model airplanes to move various wing and rudder surfaces. He referred to the following statements that I made concerning their use with robot arms:

"The advantage of using R/C servos is the positional feedback. "Potentiometric feedback, as in R/C servos, allows the controlling computer to know where each joint is positioned."

Alex countered with the following:

FIGURE 6. Robotis Dynamixel AX-12.

FIGURE 7. Robotis Dynamixel RX-28.

FIGURE 8. Line of servos from Pololu.

"There are no feedback mechanisms built into any standard servo today with the exception of the AX-12+ (the servo from Robotis and several others in that line) and a few specialized servos used in biped type robots." Alex knows servos as President of CrustCrawler, a business he started six years ago with the HexCrawler and QuadCrawler.

The products he feels have the most promise today are probably the AX12 Smart arms designed around the Robotis smart servos that I'll discuss later. However, it is CrustCrawler's and the other well-known suppliers of ready-to-roll robots and kits that have steered the servo manufacturers into designs that are made specifically for robot experimenters.

I felt that the best way to understand where he was coming from was to talk with him personally. "When I talk about servo feedback," he told me, "I mean feedback to an external controller. Feedback that is limited to the servo itself without feedback to an external controlling/monitoring device such as a microcontroller or host computer limits the usefulness of the servo motor substantially." I convinced him that I was speaking of the feedback of the internal potentiometer to the internal circuitry, not to the outside world. Its internal feedback pot serves only to tell the internal circuitry just where the servo horn is positioned.

I feel that this is an advantage over the use of a stepper motor as a stepper can become stuck and the microcontroller will assume that it still has moved the required number of turns. A microcontroller connected to a typical servo will send the appropriate series of specific width pulses and the servo will continue to try to move to the right spot until it is there.

Intelligent Servos

Alex feels that the standard servo of today — whether analog or digital — will soon be phased out for walking robots, especially the higher end kits and ready-builts. The 'Robot Exclusive Actuator Dynamixel' from Robotis is one of the most innovative servos to come out in years. The Robotis line of rotary actuators (as they call them) have some very good features for robot experimenters. They certainly command a premium price but humanoid builders will find one feature very useful in their designs — the ability to be daisy-chained rather that have three leads from each of, say, 18 servos leading back to a controller board.

Dynamixel actuators, such as the AX-12+ (Figure 6), speak to each other through a TTL line, and units such as the RX-28 (Figure 7) communicate through the popular RS-485 protocol. CrustCrawler has developed the AX12 Smart arm that uses the Robotis Dynamixel actuators for the arm's joints. Each servo in the daisy chain is assigned an address for control and feedback purposes. Yes, these devices have true feedback to the controlling microcontroller, such as an Atmel or BASIC Stamp.

Most of the larger manufacturers and dealers of robots and robot kits in *SERVO Magazine* have numerous styles, costs, and capabilities of servos in their lineups. Figure 8 shows a line of servos from Pololu. The Seattle Robotics Society (SeattleRobotics@yahoogroups.com) has excellent sources for hacking and modifying servos as do many other group's sites. R/C and model aircraft sites offer much useful information.

In the two months that I have been working on this article off and on, I have come across so much information on the subject of servos and many of the articles are completely contradictory with others. So, don't take everything that you read as fact. Talk with fellow robot experimenters and just take one apart and determine how it works and what you're going to do with it next. Modern servos are a true bargain. SV

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