INDUSTRIAL AUTOMATION

R2 SERIES OPERATORS MANUAL

Mechanical Section

Model R2-X2 eXperimental Model

Cover artwork by John Jongsma

Mechanical Systems

This section of the manual provides a description of the many of the different mechanical assemblies in your R2 Series Astromech droid.

Dome Pie Panels:

Dome pie panels are capable of opening to allow internal mechanisms such as the periscope, life-form scanner or light saber launcher to extend out from the dome. The pie panels are hinged on the bottom edge and are opened and closed via servo motors or sometimes even solenoids are used. The most widely used hinges for the pie panels are Robart hinges. They provide an arching motion as the pie panels open and close to account for the curved bottom edge of the pie panel. Other droids have used similar one piece conceal hinges from McMaster-Carr. The hinges are secured to the inside of the dome and pie panels by either using JB Weld epoxy or are fastened with machine screws.

Figure 1: Two-piece Robart hinges

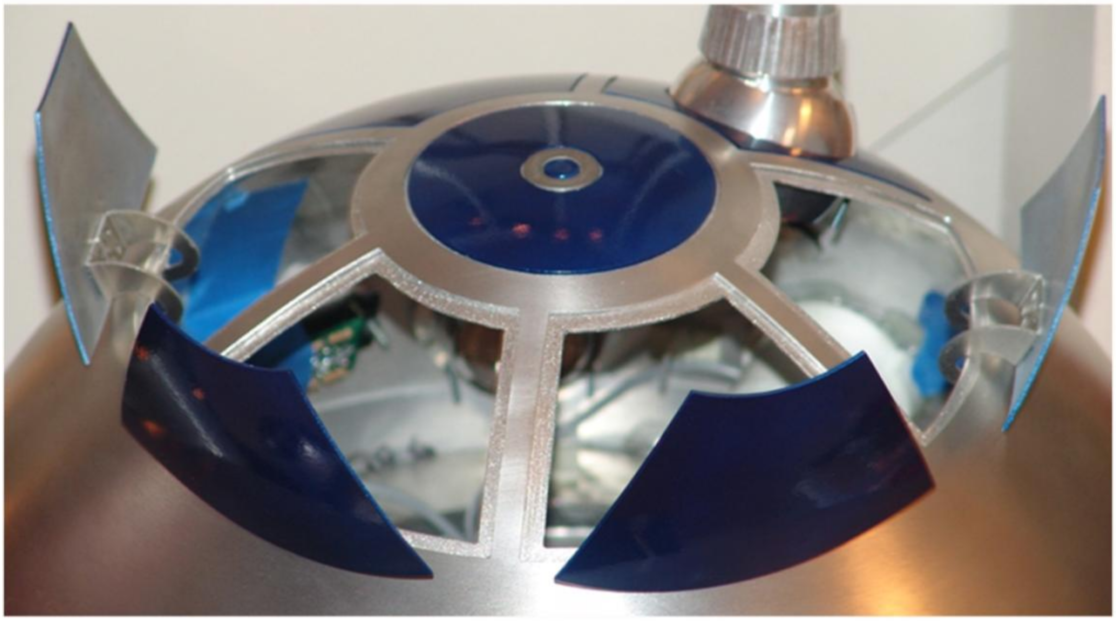

Figure 2: Dome pie panels with Robart hinges

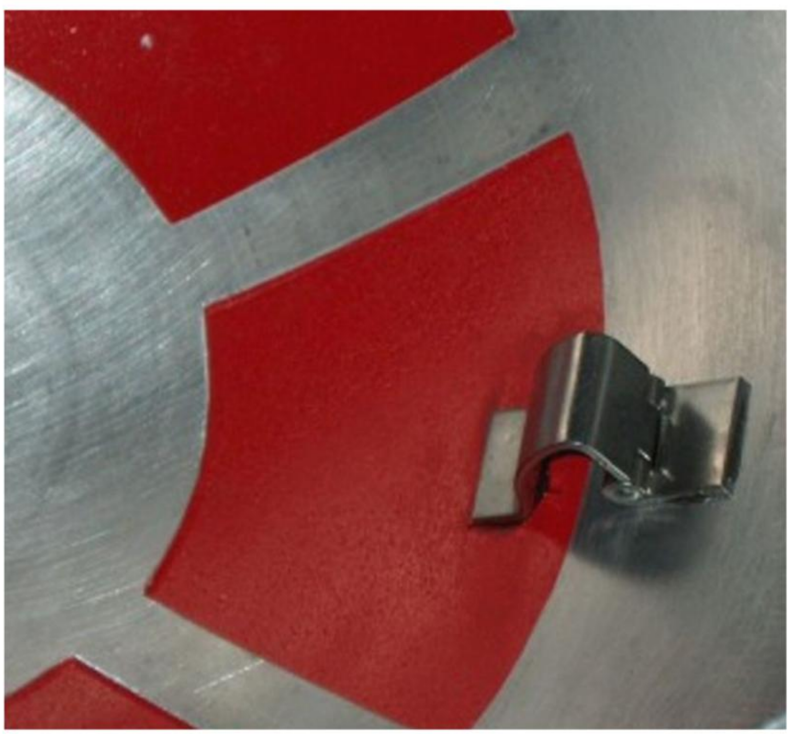

Figure 3: Pie panel hinged (inside view) – reveal hinges

To mechanize the pie panels open and close motion servo motors are used. The servo motor are typical hobby servos and are often the smaller servos such as the (HiTEC HS-225BB mini servo) since they take up less real estate when mounted inside the dome. The same servo motor and hinge setup that is used to open and close the pie panels is also used on the lower dome panels. The servos are often mounted on foundation blocks that have a curvature to match the inside of the dome. This provides a good surface to surface contact when adhering the servo mount to the inside of the dome.

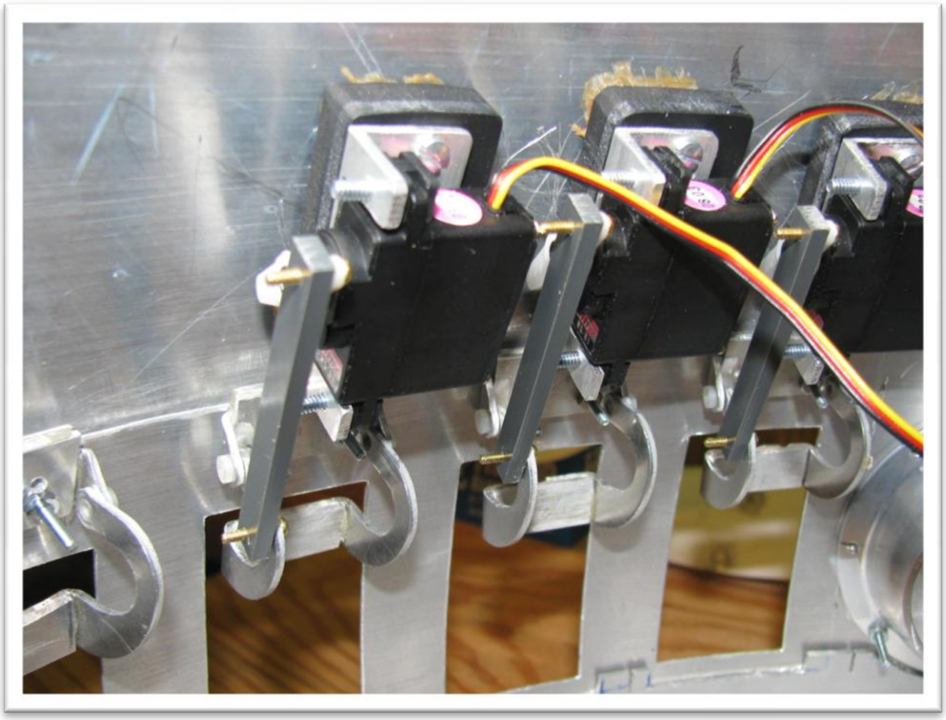

Figure 4: Lower dome panels hinged and controlled by servos **- Photo by: Bob Ross**

Dome Fire Extinguisher:

An optional piece of equipment installed in some R2 series droids is a “fire extinguisher”. Most droids have them mounted in the dome but a few have them mounted in the body. The “fire extinguisher” which is a can of compressed air is typically mounted upside down in the dome with a hose routed to a nozzle mounted behind one of the lower dome panels. The “fire extinguisher” is triggered by a solenoid that is attached to the trigger on the can of compressed air. An RF relay is used to activate the solenoid that pulls the trigger on the can of air and releases the spray from the open lower panel.

Figure 5: Compressed air can upside down with solenoid trigger **- Photo by: Tiny P.**

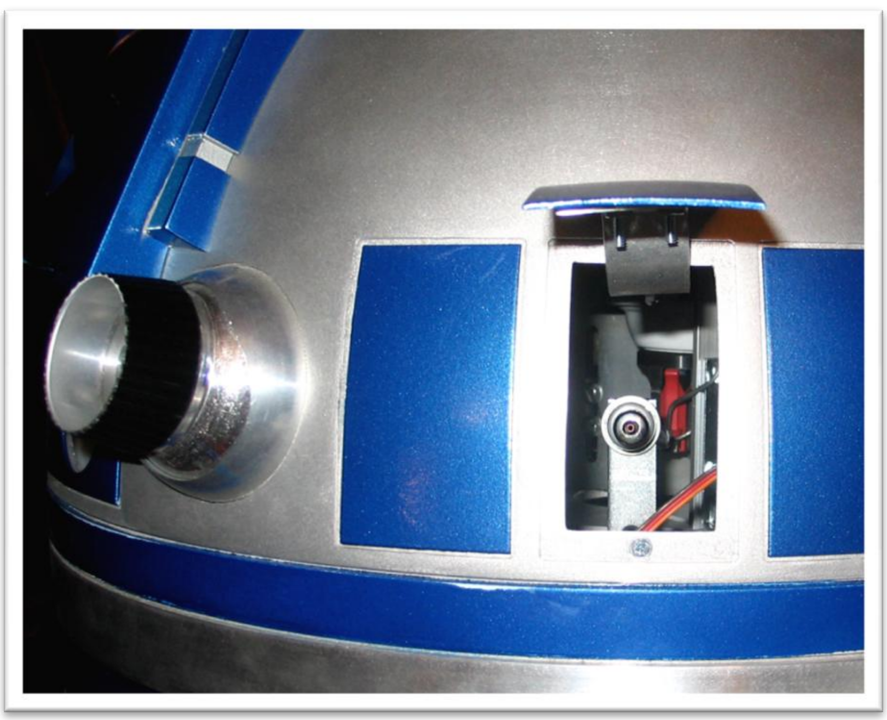

Figure 6: Fire extinguisher nozzle behind lower pie panel **- Photo by: Corey Pacione**

Dome Life-form Scanner:

Some astromech droids are fitted with a life-form scanner which is a mechanism that extends a semi-circular shaped screen from one of the top dome pie panels. The life-form scanner mechanism is a particularly tough mechanical challenge as it extends up to 25" out of the dome while the dome itself is only approx. 9 inches tall where the scanner is mounted within the dome. Some very clever droid builders have successfully used an electric telescoping car antenna to make this mechanism work. The life-form scanner screen and body are mounted on the end of the telescoping antenna and the electric motor raises and lowers the scanner from an opened pie panel.

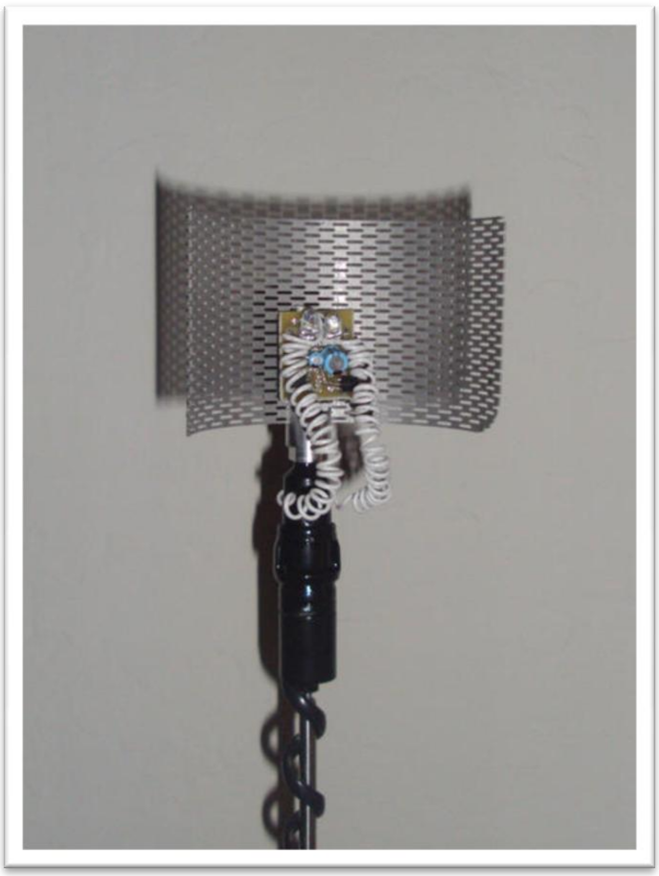

Figure 7: Life-form scanner screen and body **- Photo by: Tiny P.**

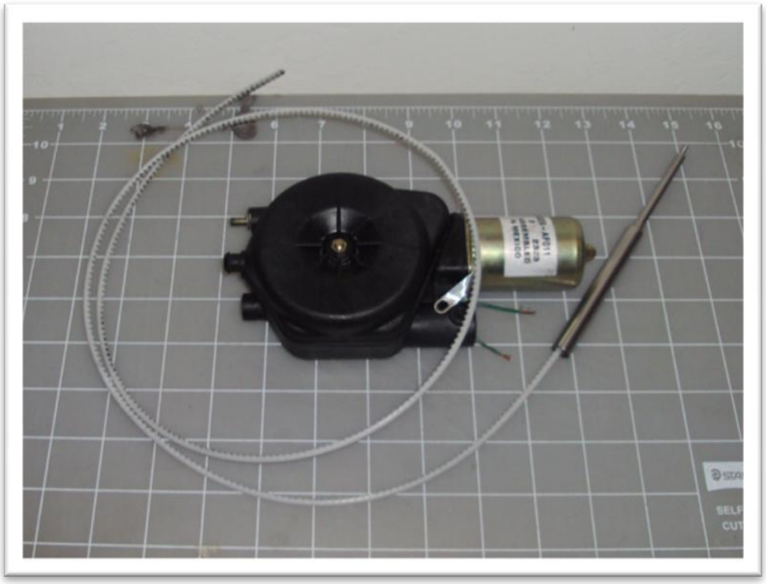

Figure 8: Telescoping antenna mechanism **- Photo by: Tiny P.**

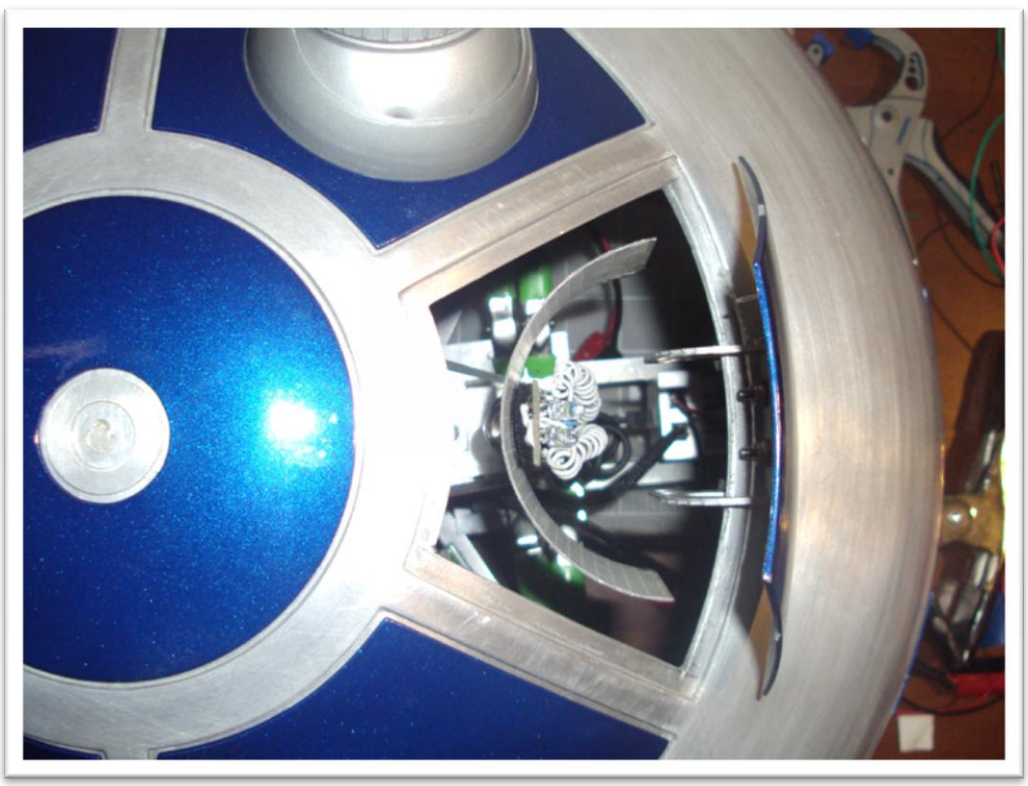

Figure 9: Life-form scanner in dome top view **- Photo by: Tiny P**.

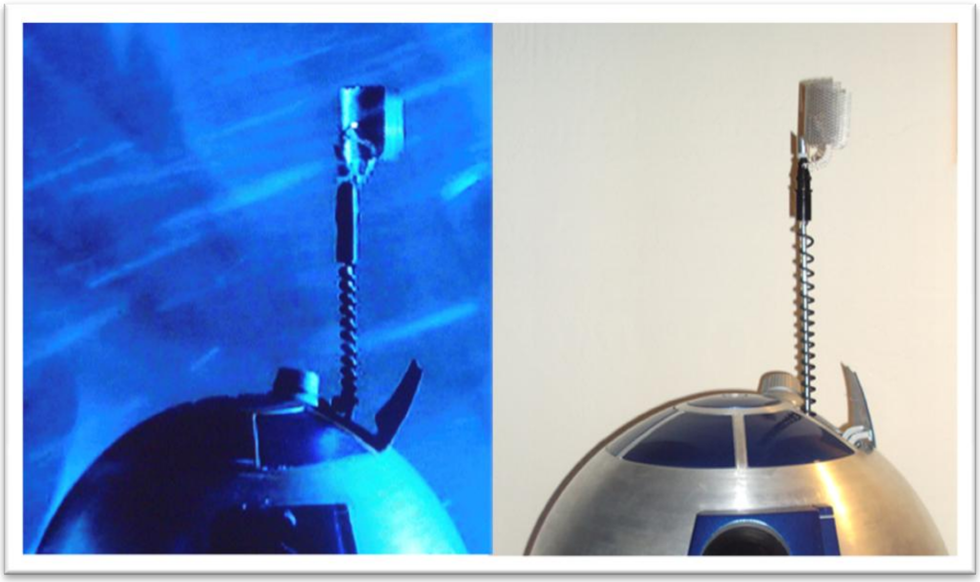

Figure 10: Life-form scanner comparison - **Photo by: Tiny P.**

Periscope Lifter Mechanisms:

The periscope lifter mechanisms most builders have constructed work differently from the life-form scanner lifter. Periscope lifters have a different set of requirements and thus the reason for the different designs. Periscope lifters need to lifter a larger payload and be able to rotate the periscope once it reaches the top of its extension. They also do not need to lift the periscope as high as the life-form scanner. This opens up other possible mechanisms for doing the lifting. A brief list of the types of mechanisms builds have used to build periscope lifters is as follows:

1. **Lead screws:** This consists of a vertically mounted threaded rod that is rotated by a motor. A lead nut is moves up and down the threaded rod as the threaded rod turns. A platform to hold the periscope is mounted to the lead nut to do the actual lifting and lowering of the periscope. The Daniel Deutch periscope lifter is an example of this type of mechanism.

2. **Wire and pulley:** Wire and pulley systems use a motor and pulleys and a spool to move a wire along a circuit of pulleys. The wire is strung through pulleys along the vertical axis of the lifter mechanism and end being wrapped around a spool. The lifting platform is mounted to a single point on the wire. As the motor turns one end of the wire unwraps from the spool while the other end wraps around the spool. This keeps the wire from developing any slack. When the motor reverses the opposite wrapping and unwrapping happens. The Tiny P. lifter is an example of this type of mechanism.

3. **Rack gears**: The rack gear system consists of a fixed vertically mounted rack gear and a motor with a spur gear meshes with the rack gear. As the motor turns the motor “crawls” its way up or down the fixed rack gear. The A&A and Craig Smith lifter mechanisms are examples of rack gear lifters.

Production Periscope Lifter Mechanisms:

Figure 11: Single lifter mechanism **- Photo by: Daniel Deutch**

Figure 12: Periscope lifter – A&A

Custom Built Lifter Mechanism:

Droid builders have also built their own custom periscope lifter mechanisms.

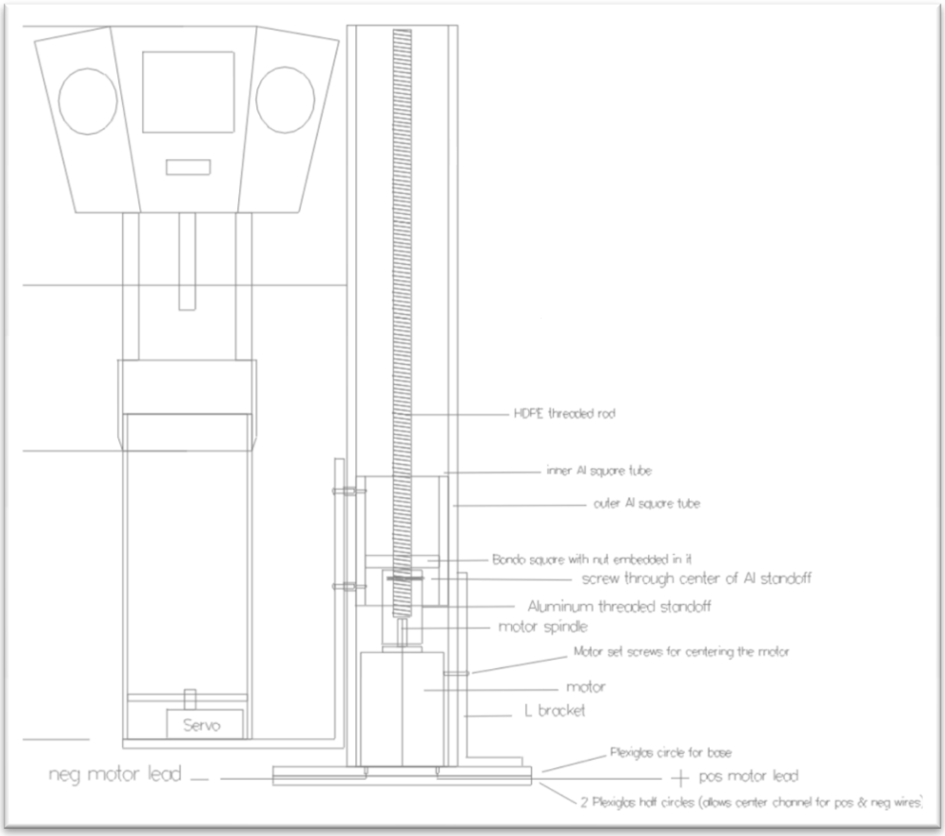

Figure 13: Periscope lifter mechanism **– Concept drawing by: Blake Mann**

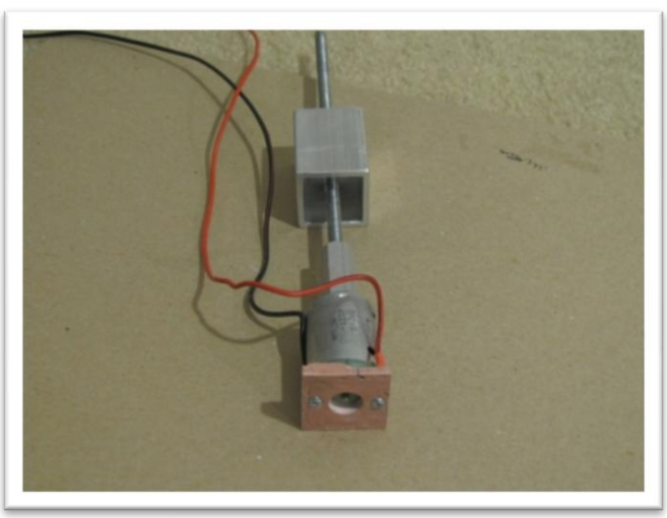

Figure 14: Custom periscope lifter – internals

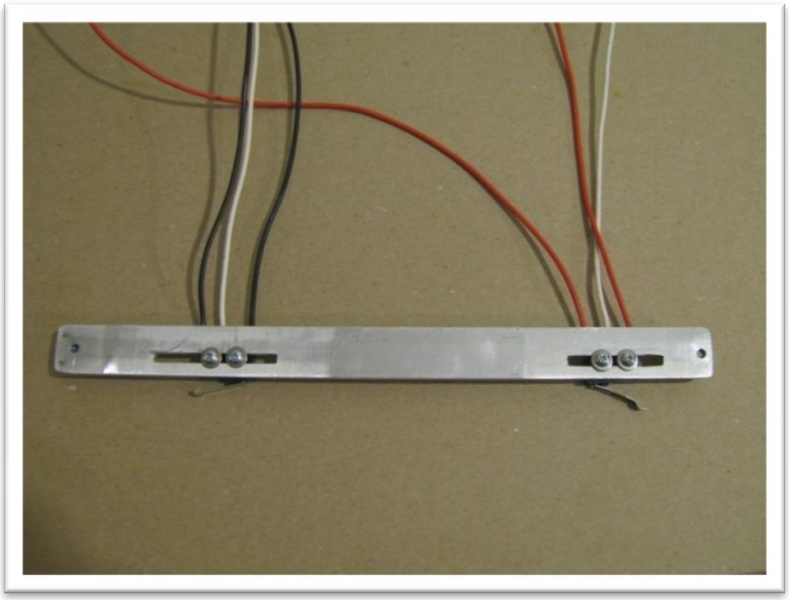

Figure 15: Custom periscope lifter – adjustable limit switches

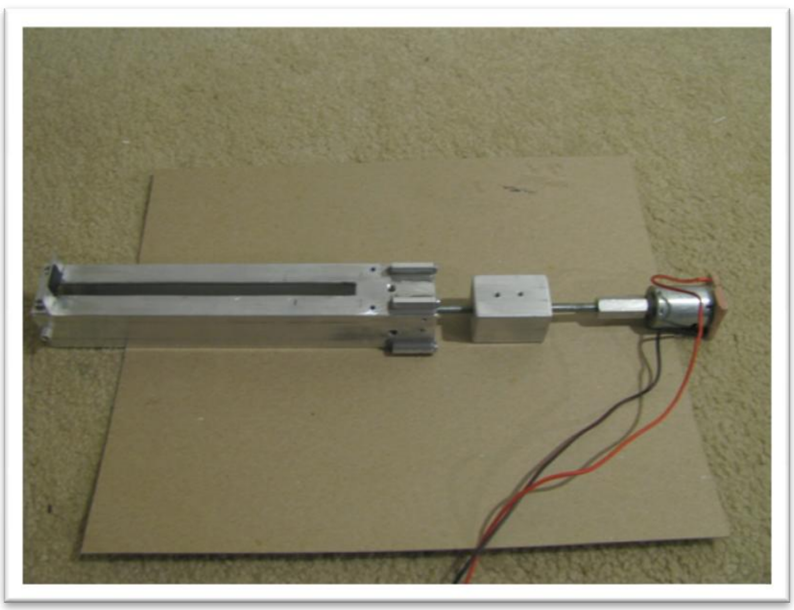

Figure 16: Custom periscope lifter – pre assembly

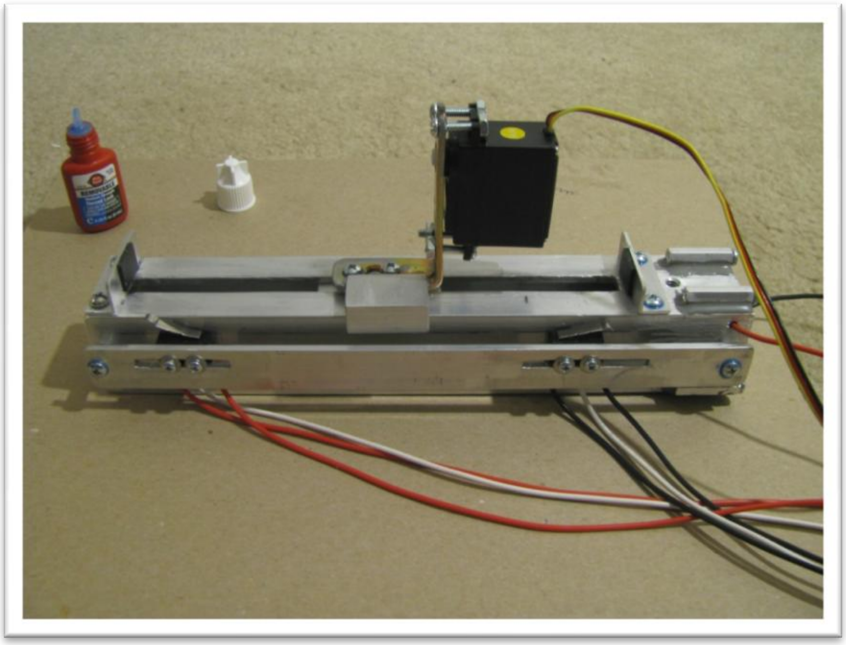

Figure 17: Custom periscope lifter – Assembled

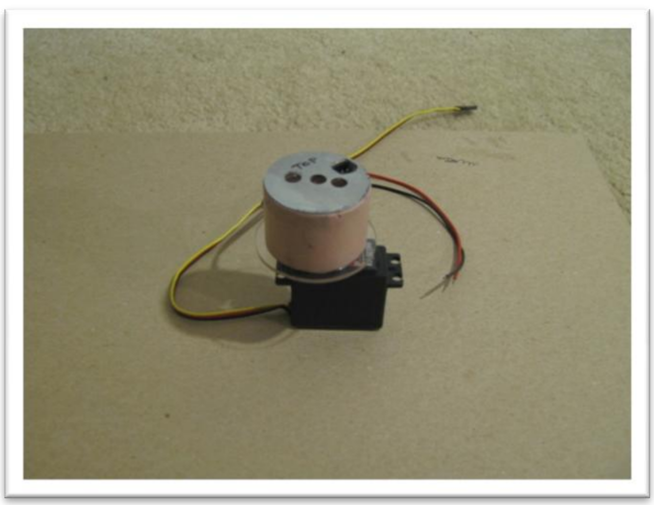

Figure 18: Custom periscope lifter – Periscope base socket mounted on a servo

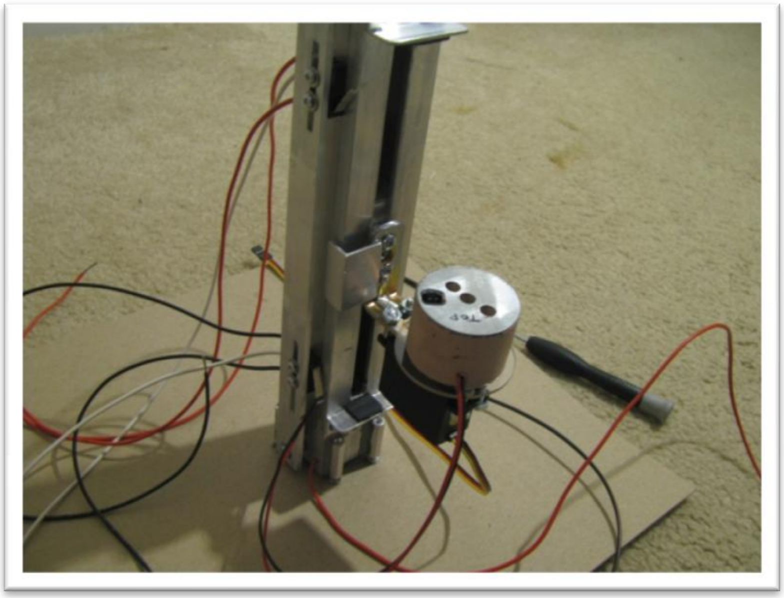

Figure 19: Custom periscope lifter – periscope base socket

Figure 20: Custom periscope lifter – periscope mounted on servo base socket

The mechanics of the lifter mechanism may differ significantly but most lifters employ a similar electrical mechanism to make them work. Lifter mechanisms use limit switches on each end of the motion to stop the motor. The wiring of the limit switches along with a double pole double throw relay causes the motor to reverse direction when the lifter reaches each end of the motion. This allows a single button on a RF remote to signal the periscope to move up or down.

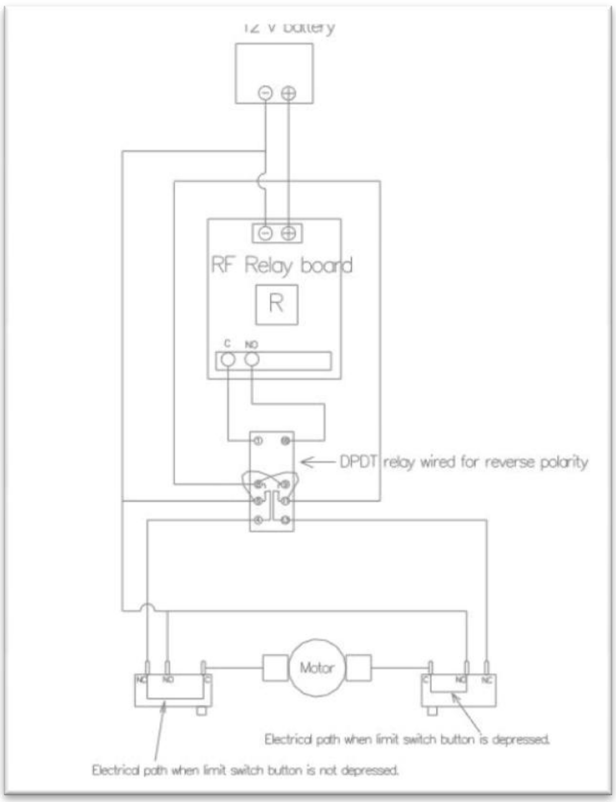

Figure 21: Periscope lifter wire diagram **– Diagram by: Blake Mann**

Other Custom Built Lifter Mechanisms:

Figure 22: Custom built periscope lifter **- Photo by: Tiny P.**

Figure 23: Life-form scanner lifter **- Photo by: Craig Smith**

R2-X2 eXperimental Dome Quad Lifter Mechanism:

The R2-X2 eXperimental Astromech droid is equipped with a prototype Quad Lifter mechanism used for lifting the periscope and the life-form scanner as well as the dome battery packs. The prototype quad lifter mechanism is an all-in-one mechanism that provides the lifting and lowering motions for the dome periscope, life-form scanner and one additional dome utility mechanism that exit from the top dome pie panels. The quad lifter also provides the lifting and lowering motion for the center dome battery packs that exits from the center dome round panel. The housing of the quad lifter is a 5" PVC pipe with channels cut for the mounting brackets that lift and lower the dome mechanisms. The lifting and lowering of the outer dome mechanisms is accomplished by 3 lead screws inside the PVC pipe. Each of the leads screws is rotated by one of 3 small motors mounted inside the quad lifter. The motors use spur gears attached directly to the shaft of the motor to turn a second gear attached to the lead screw. The lifting platform that the periscope rests on is attached to a lead nut that moves up or down depending on the direction of the lead screw rotation. A center servo motor that has been modified to spin continuously is mounted in the center bottom of the quad lifter turns the center lead screw which lifts the center battery packs. Once the battery packs are lifted from the dome they can be swapped out with fresh battery packs.

Figure 24: R2-X2 eXperimental quad lifter **- Photo by: Blake Mann**

Holo-Projector Movement:

The holo-projectors are capable of independent movement. The mechanism to move the holo-projectors was designed by Chris Howes and manufactured by A&A. The mechanism provides a housing that the spherical body of the holo-projector is mounted in and allows it to be angled in any direction up to about 10 degrees. Movement is accomplished by two servo motors that move two sliding arms which in turn move a pin that protrudes from the back of the spherical holo-projector body (see figures below). The holo-projectors movement can be remotely operated by attaching the servos to an RC transmitter/receiver or they can be activated by a micro controller either in a programmed/random movement or in response to sensor data.

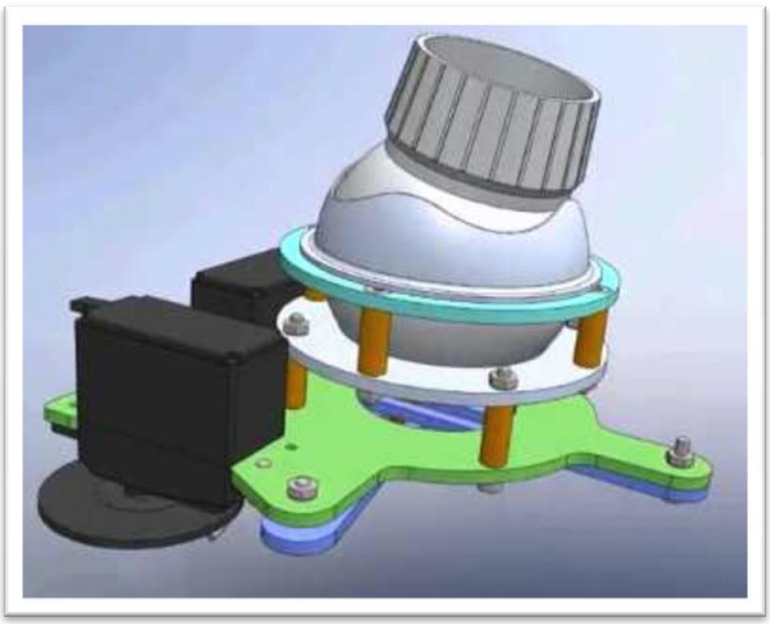

Figure 25: Holo-eye mechanism concept view 1 **- By: Chris Howes**

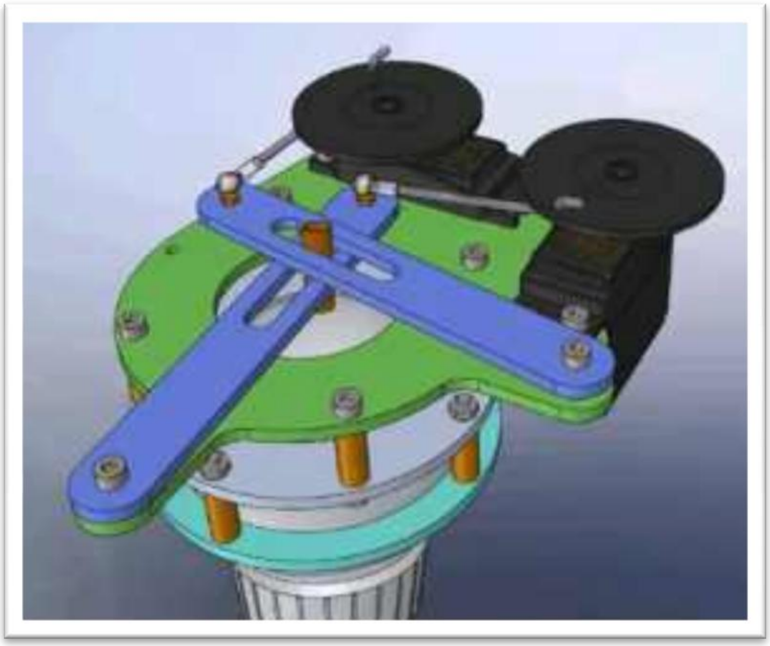

Figure 26: Holo-eye mechanism concept view 2 **- By: Chris Howes**

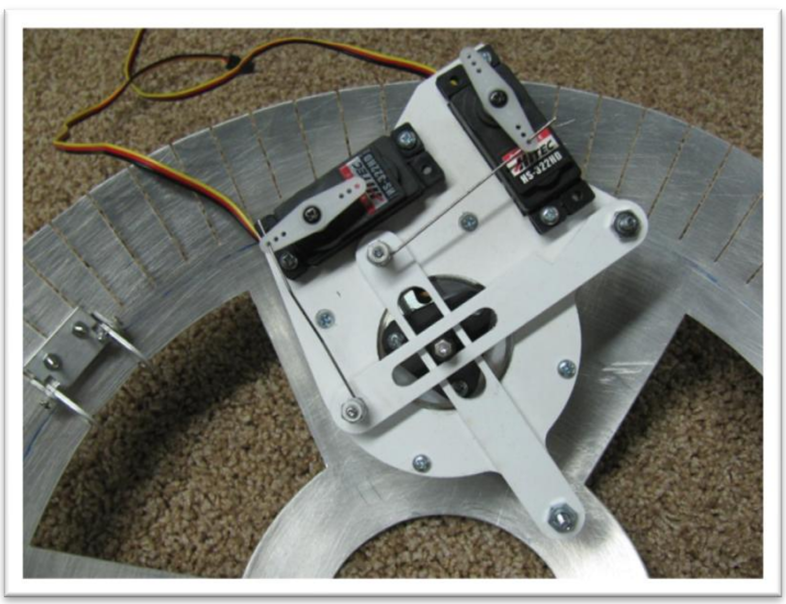

Figure 27: Holo-eye mechanism assembly **- Photo by: Bob Ross**

Dome Rotation Drive:

The R2-X2 droid is equipped with a direct drive dome motion system. The dome rotates via a motor with an attached gear that meshes with ring gear mounted to the Rockler dome bearing.

Figure 28: Motor with A&A gear attachment

The motor used to rotate the dome is a Pittman GM9413L275. The motor specs are listed in the appendix of this manual. The motor is a gear-head motor with a 19.7:1 gear ratio. These motors produce significant torque by utilizing a gearing system housed in the "head" of the motor assembly. The gear that mounts to the motor shaft as well as the ring gear that mounts to the Rockler bearing are an A&A Gear ring set. The motor is mounted to the frame with a flat aluminum plate and is positioned precisely so that the gear on the motor shaft meshes with the gear mounted on the Rockler bearing. The motor is powered by the 12 volt internal battery and its speed is controlled by a SyRen 25 Amp motor speed controller from Dimension Engineering (specs for the SyRen are listed in the Appendix).

Figure 29: Pittman gear-head motor

Figure 30: A&A gear ring set

Other droids use a simple dome wheel drive system that rotates the dome with a wheel that uses friction to turn the dome. This also works well, and both systems have advantages and disadvantages. The friction wheel dome drive uses a swivel bracket to hold the drive motor so that the drive wheel can be pulled tight against the Rockler dome bearing with a spring. The spring provides enough friction for the wheel to turn the dome yet if the dome were to be stopped by hand the wheel would be allowed to slip preventing the motor from stalling.

Figure 31: Aluminum dome drive bracket & spring **- Photo by: Atomic Pickle**

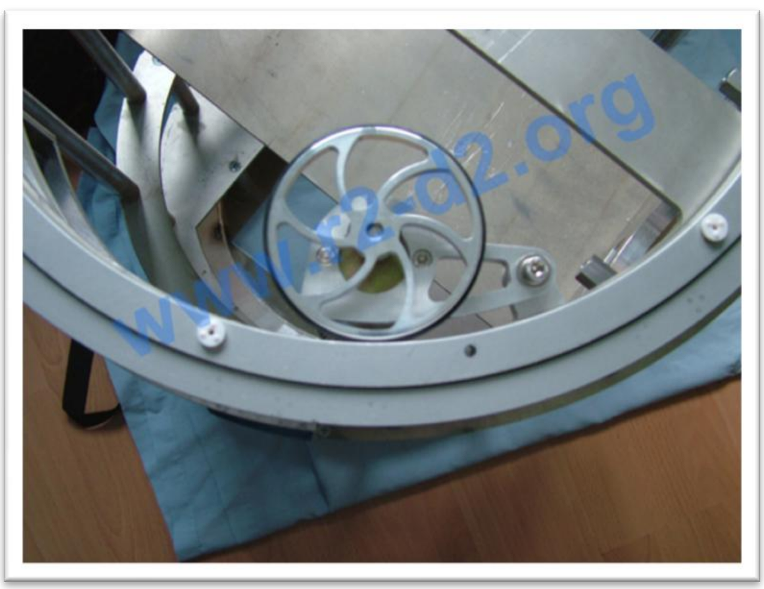

Figure 32: Dome wheel drive – Atomic Pickle

CPU Arm:

Some R2 series droids are equipped with the CPU interface arm. The intended purpose of this device was to physically establish a connection to a stationary computer system to either exchange information or execute commands on the remote system. The CPU arm is stored in a downward facing direction behind the droids front right panel. When the door opens the arm rotates upward and extends out from the body of the droid. This allows it to be in position to extend out further so that it can make connection with a wall mounted computer communications port. The top end of the CPU arm is mounted on the shaft of a gear-head motor. When the motor turn it rotates the CPU arm up into the extended position. Once it is in the extended position a secondary motorize telescoping antenna mechanism is used to extend the forward section of the CPU arm further out while simultaneously spinning the head of the CPU arm.

Figure 33: CPU arm mounted behind the front vertical panel **- Photo by: Cory Pacione**

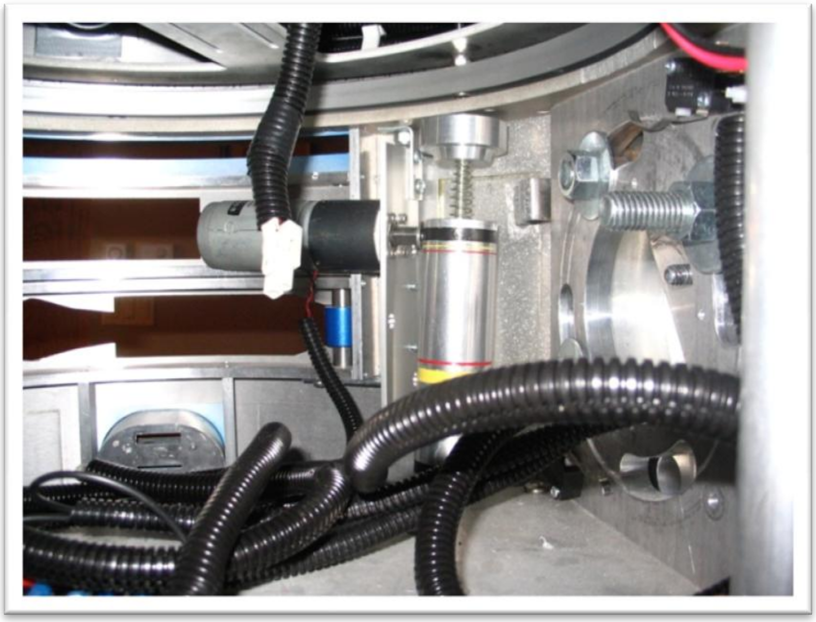

Figure 34: CPU arm mounted on the shaft of a gear motor **- Photo by: Cory Pacione**

Utility arms:

The R2 series droid uses its utility arms as the main manipulation mechanisms while they are supplemented by the mechanical gripper arm. Some builders have mechanized the utility arms by connecting a servo and linkage to each arm from the back side. This allows the utility arms to swing open when remotely actuated.

Figure 35: Utility arms mechanized

Figure 36: Utility arms mechanized with a servo

Skin Panels:

The skins provide the outer body covering but they also have number of panels and doors that open to allow internal mechanisms to extend out from the body. Several different types of hinges are used to make doors and other panels on the skins open and close.

Figure 37: Back door (outside view) hinged with Robart hinges **- Photo by: Chip Luck**

Figure 38: Back door (inside view) hinged with Robart hinges **- Photo by: Chip Luck**

Figure 39: Front panels hinged **- Photo by: Chip Luck**

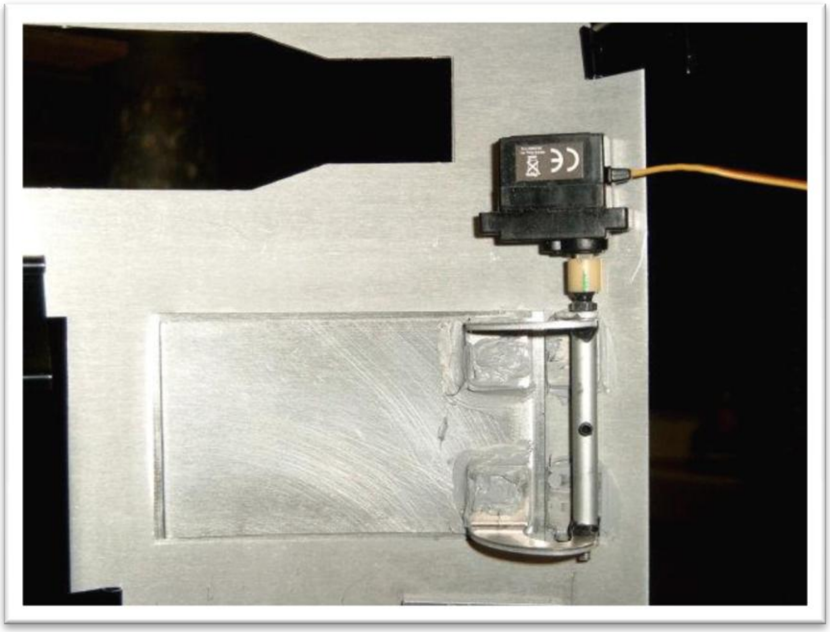

Figure 40: Skins door panel mechanized with a servo

Figure 41: Front door panel mechanized with a servo

Mobility System Mechanics:

The R2-X2 eXperimental edition Astromech droid is equipped with a prototype foot drive mechanism. The major components of the drive mechanism consists of the following.

1. A steel shell that provide the mounting points for the other components of the drive system. The steel shell is made from 3/16" steel plate that has been water jet cut and bent to form the shape that will fit inside the JAG steel foot shells.

2. An aluminum horseshoe that has been CNC machined from T6-6061 aluminum. The aluminum horse shoe bolts to the steel drive shell and lends additional lateral support to the steel shell preventing it from flexing. Holes in the side members of the aluminum horseshoe support the ½" steel axle for the rear wheel.

3. Traction wheels provide the driving force to move the droid. The Traction wheels use ball bearings mounted in the center of the wheel to provide smooth spinning of the rear wheel on the axle.

4. Front omni wheels mount on a 3/8" steel front axles. These axles are supported by two bronze mounts bolted directly to the inside of the steel drive shell.

5. EV Warrior motors drive the rear wheels mount in the center of the foot drive shell. They are mounted using aluminum motor mounts that are bolted directly to the top inside of the foot drive shell with 4 machine screws.

6. Two steel sprockets connected by #25 roller chain drive the rear traction wheel. One sprocket mounts directly to the shaft of the EV Warrior motor and the other mounts directly to the Traction wheel.

Two drive motors, one in each foot housing, provides the droid's mobility. The two drive motors are Bosch EV Warrior motors and are powerful enough to move the droid on difficult terrain.

Bosch EV Warrior Drive Motor Specifications:

Weight:	3.24 lb	No Load RPM:	12v: 2210 rpm	24v: 4480 rpm
Diameter:	4.0"	Peak Horsepower:	12v: .378 hp	24v: 1.55 hp
Length:	2.72"	No Load Current:	12v: 2.6A	24v: 2.6A
Shaft:	8mm diameter x 30mm	Stall Current:	12v: 99.2 A	24v: 198 A
		Stall Torque:	12v: 691 oz-in	24v: 1400 oz-in

The foot drive housing is a one piece 3/16" thick steel frame that the motor, the traction wheel and the omni wheel mount to. The aluminum horseshoe bolts to the inside of the shell and holds the back axle that the traction wheel mounts on.

Figure 42: R2-X2 eXperimental steel foot drive shell **- Photo by: Blake Mann**

Figure 43: R2-X2 eXperimental Aluminum axle horseshoe**- Photo by: Blake Mann**

Traction Wheels:

IFI (Innovation First Inc.) Traction wheels are a pre-manufactured drive wheel. The IFI Traction wheels are machined aluminum pieces that bolt together to form the wheel. The center of the wheel has ball bearings to allow the wheel to spin freely on the axle. The Traction wheels have a traction strip that mounts onto the circumference of the wheel. Different traction treads are available.

Figure 44: IFI Traction wheels

Omni Wheels:

Acroname omni wheels used in the front of the drive to allow the droid to spin in place for tight maneuvering.

Figure 45: Acroname Omni wheel

Dimension	80mm/3.125" O.D.
Weight	10 oz

Hub	63.9mm / 2.518"
Axle Bore	8.4mm
Roller Capacity	100 lbs.

EV Warrior Motors:

Figure 46: EV Warrior motor

EV Warrior Motor Mounts:

The R2-X2 eXperimental foot drive uses custom aluminum motor mounts to attach the EV Warrior motors to the drive unit.

Figure 47: EV Warrior motor mounts

R2-X2 eXperimental Foot Drive Assembly:

The assembled R2-X2 eXperimental foot drive is shown below installed into the JAG outer steel foot housing.

Figure 48: R2-X2 eXperimental foot drive assembled **- Photo by: Blake Mann**

Other Drive Systems:

Many different drive systems have been developed for the R2 Series Astromech droids. Each drive system has its own advantage as each designer has had a different objective in mind. Drive systems are typically designed with a specific droid weight range in mind. Therefore drive systems fall into one of several classes - the light weight droid, medium weight droid and heavy weight droid. Some of the more successful drive system include:

1. JAG Drive system – Designed for medium to heavy weight droids

2. Senna Drive system - Designed for light to medium or heavy weight droids. This drive can be geared differently for different weight classes of droids.

3. A&A drive system – Designed for light to medium weight droids

4. Custom built drive systems by (Bob Ross, Dan Stuettgen, Monty Mcgraw, Scott Powers, Peter Wishart – and many many more)

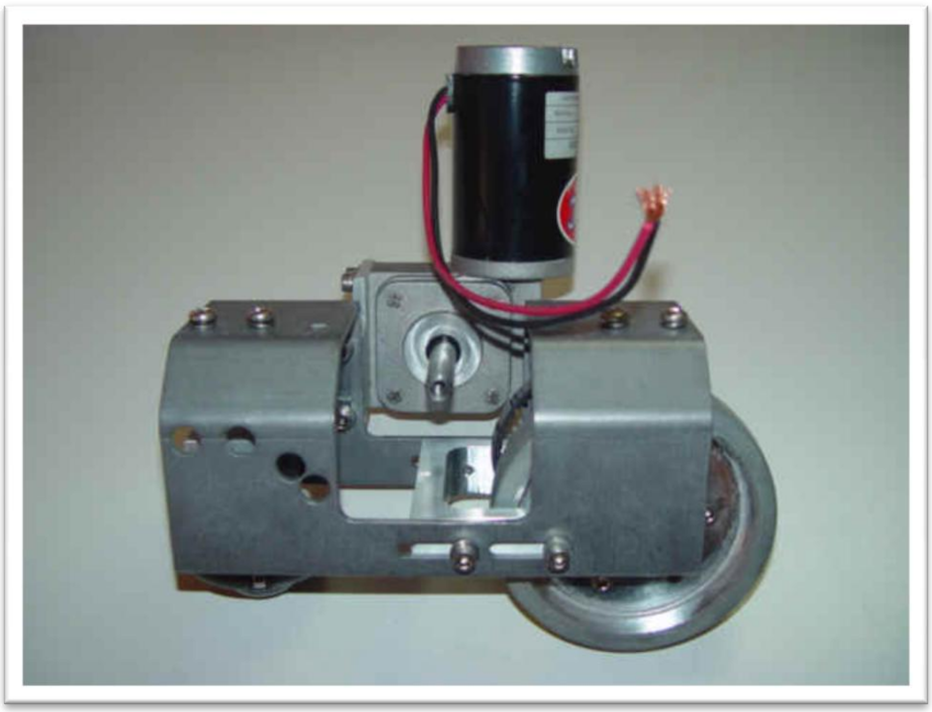

Figure 49: Foot Drive **- AP & JAG**

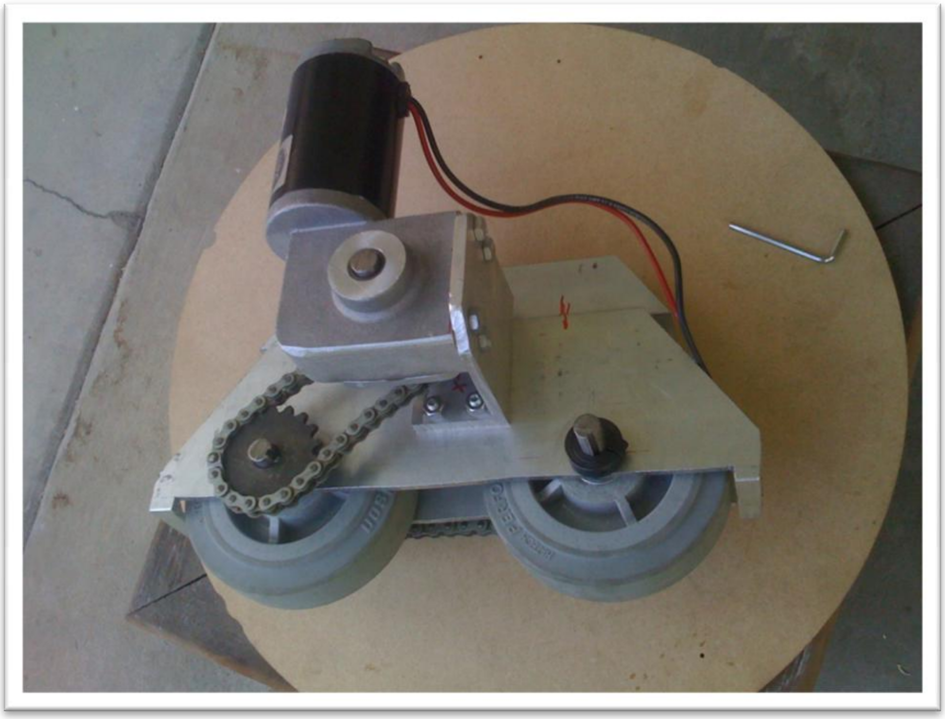

Figure 50: Foot Drive **- Mike Senna**

Figure 51: Foot Drive **- A&A**

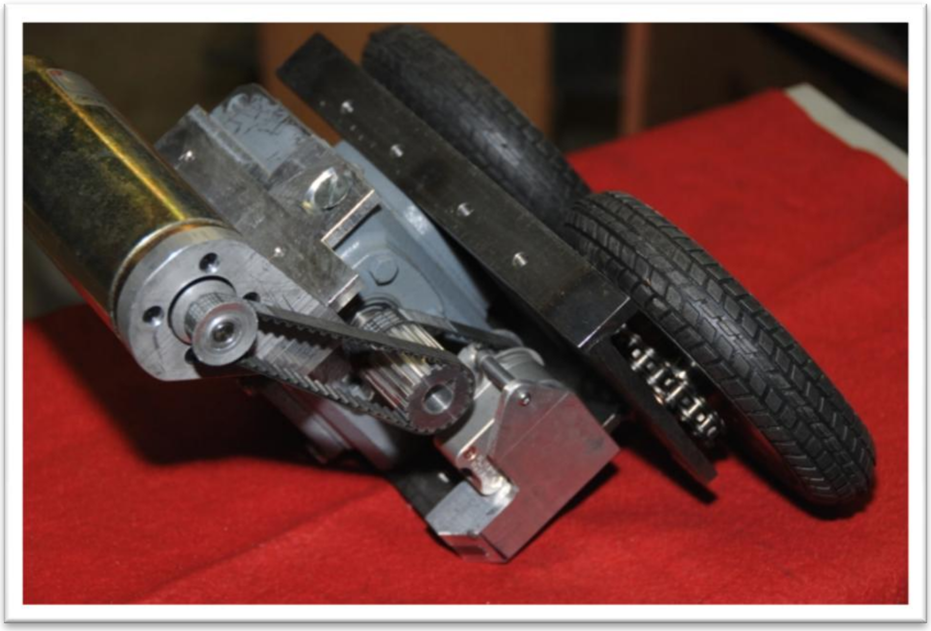

Figure 52: Custom Foot Drive **- Peter Wishart**

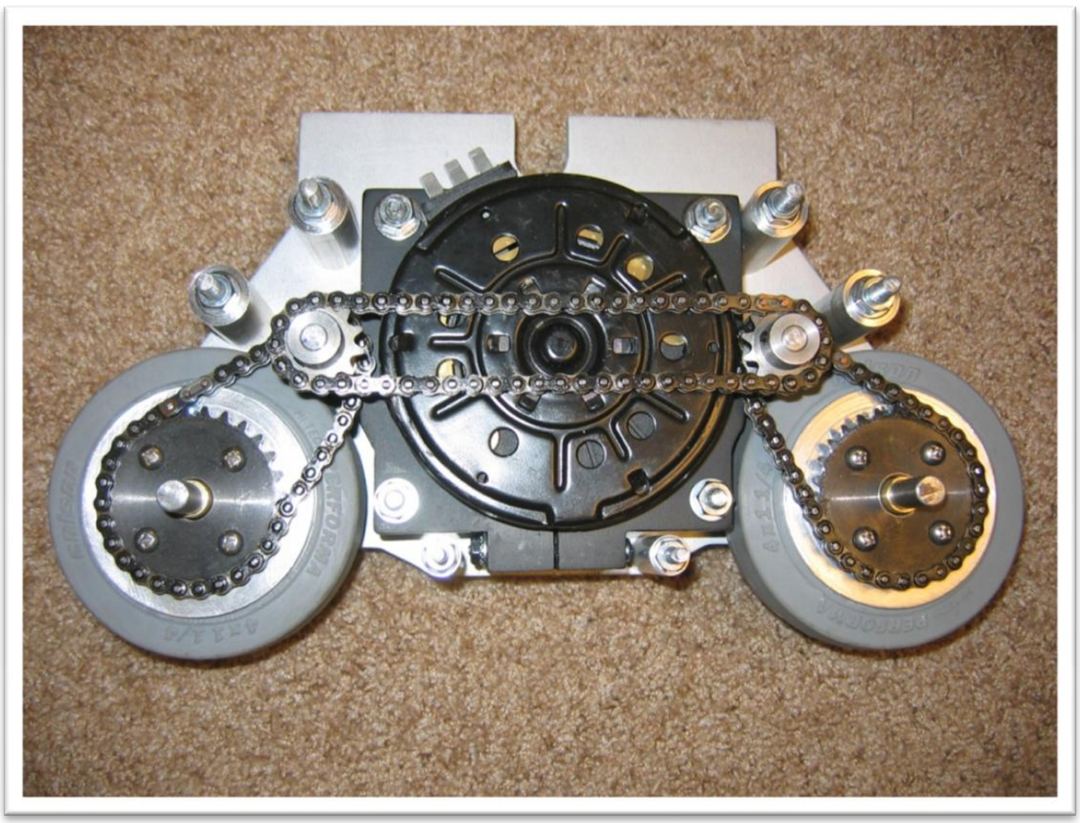

Figure 53: Custom Foot Drive **- Bob Ross**

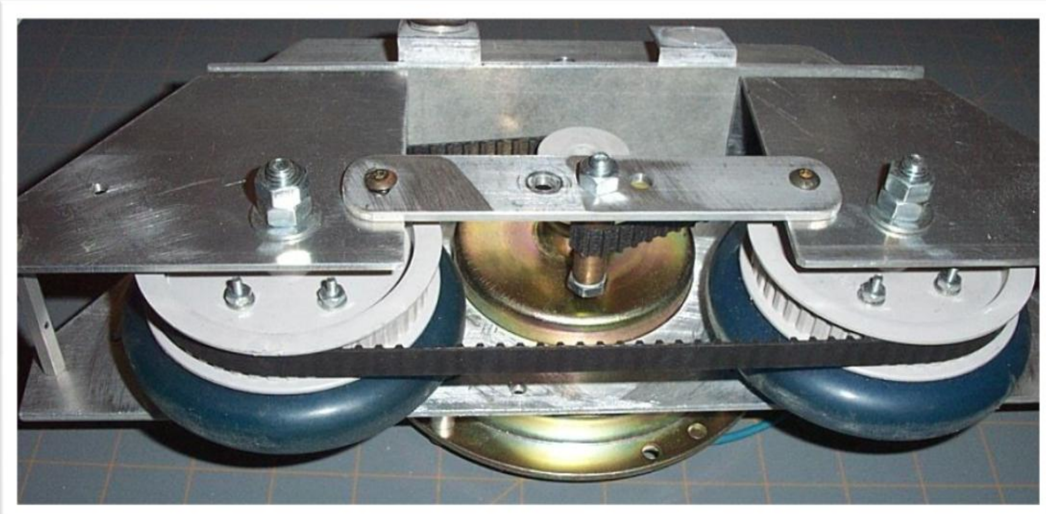

Figure 54: Custom Foot Drive **- Dan Stuettgen**

Figure 55: Custom Foot Drive **- Monty Mcgraw**

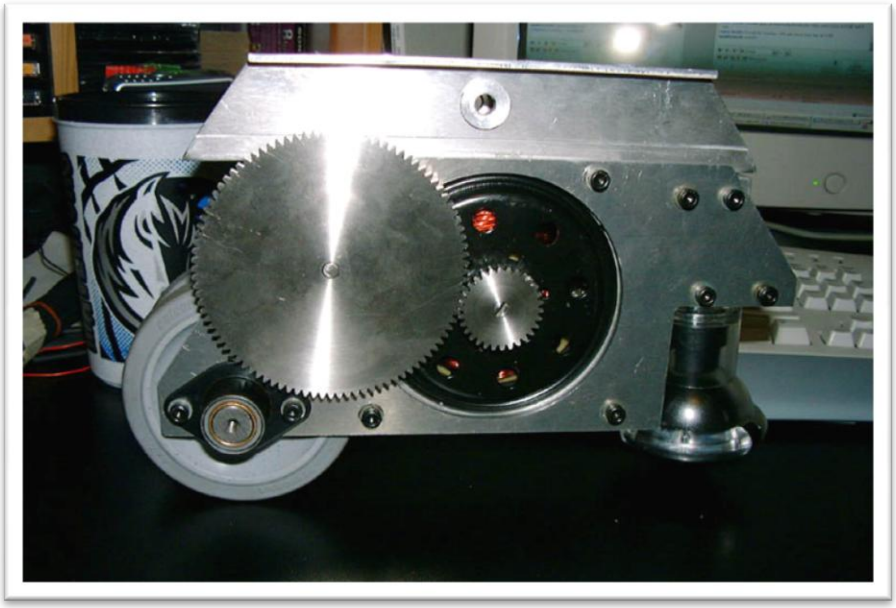

Figure 56: Custom Foot Drive **- Scott Powers**

Center foot wheel platform:

The R2-X2 eXperimental edition Astromech droid is equipped with a prototype four-omni wheel platform in the center stabilizer foot. Four Acroname omni wheels give the stabilizer foot a wide stable base and also spread the load of the foot over four wheels and therefore a larger area than the standard droid caster system. The Acroname omni wheels have a larger diameter (8 cm) than the standard caster so they roll over obstacles easier. Below is a photo of the working prototype four wheel foot bracket. The figure shows the CNC machined version of the four wheel stabilizer foot bracket that is still in the design stage.

Figure 57: Stabilizer foot omni wheel platform **- Photo by: Blake Mann**

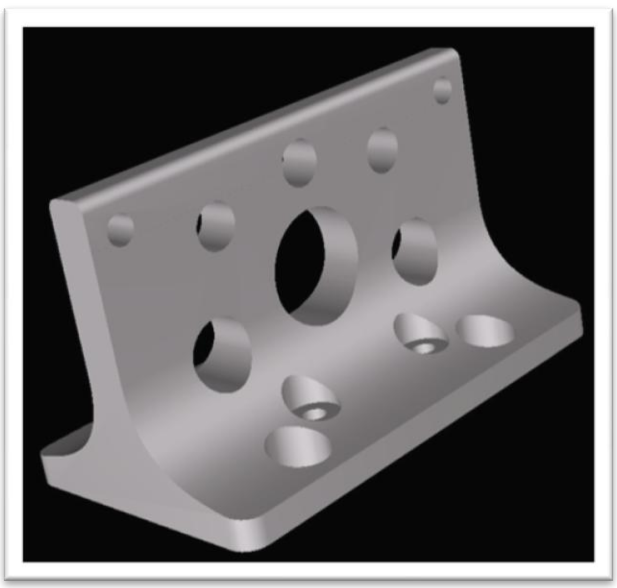

Figure 58: eXperimental CNC machine version of the stabilizer foot wheel bracket

Center Foot Shock Absorption System:

The R2-X2 eXperimental edition Astromech droid also has a prototype shock absorption system in the center stabilizer foot. The omni wheel platform is mounted to the droid with four Sorbothane vibration mounts that absorb the shock of the foot as it passed over rough terrain.

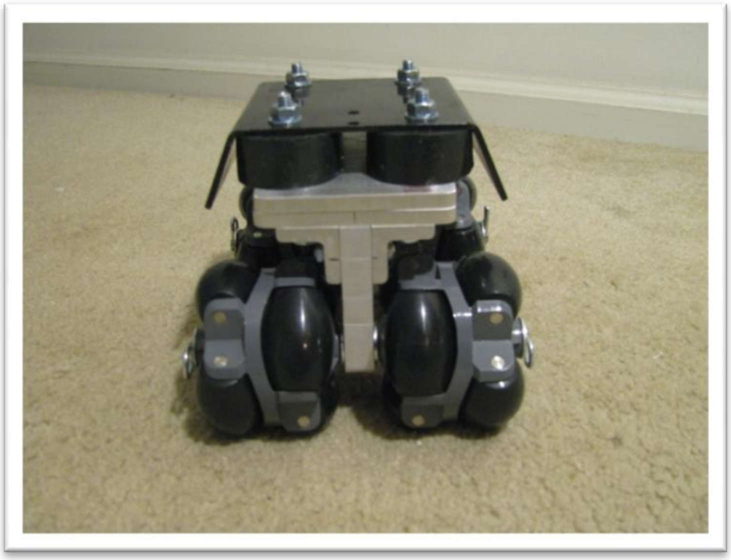

Figure 59: Stabilizer foot shock absorption mounts **- Photo by: Blake Mann**

R2-X2 eXperimental Mobility Mode System (2-3-2):

Astromech droids are designed to transition into a “mobility mode” where the stabilizer foot retracts from the center body and becomes a third foot. This provides the droid with much greater stability while traveling over rough terrain. Once the droid arrives at its intended destination the third foot retracts and it reverts to a two leg stance. The two leg stance is mostly used while the droid is performing its work as it allows the droid to get closer to the object it is working on. The complete cycle of extending and retracting the stabilizer foot is often referred to as the 2-3-2 transition. The R2-X2 eXperimental series is equipped with the latest internal mechanisms for performing the 2-3-2 transition.

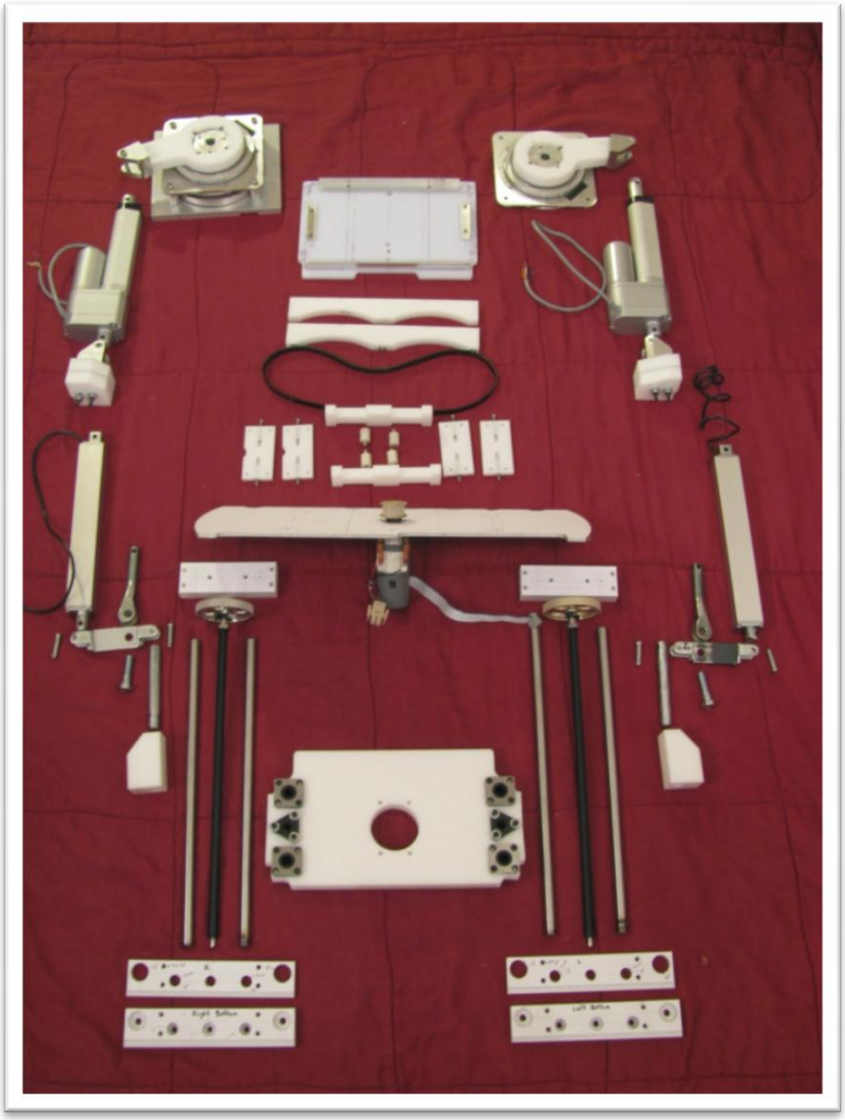

Figure 60: 2-3-2 mechanism parts layout **- Photo by: Blake Mann**

Center Foot Lift/Lower Mechanism:

The center stabilizer foot is extended and retracted via a single Pittman gear-head motor mounted vertically just below the center battery compartment. The shaft of the motor turns a timing gear which turns two lead screws via a timing belt. There is a center lift/lower plate that rides up and down on these lead screws. The center ankle is mounted directly to this center lift/lowering plate.

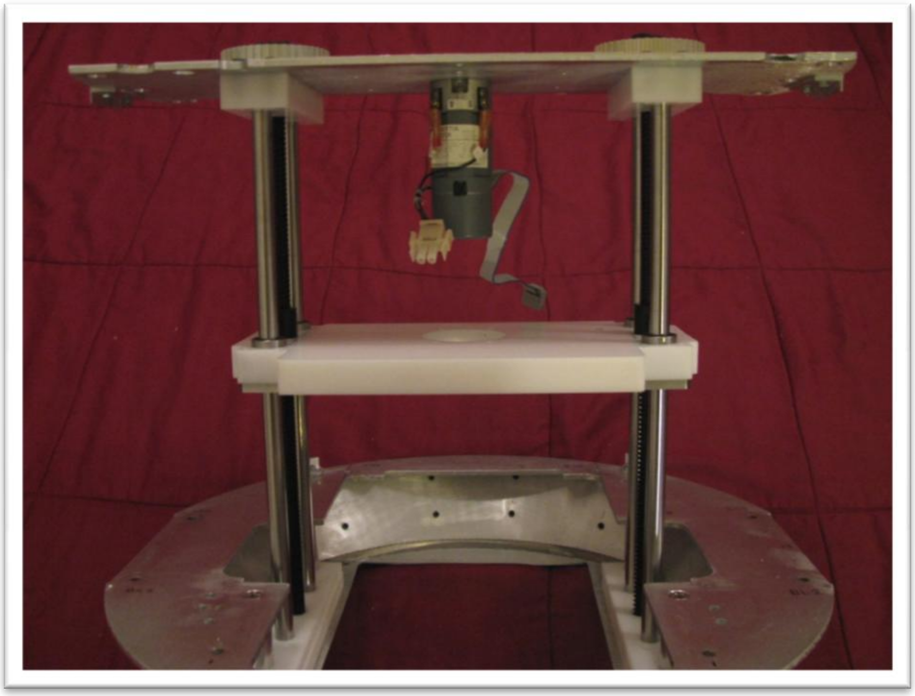

Figure 61: 2-3-2 Center foot lift/lower mechanism **- Photo by: Blake Mann**

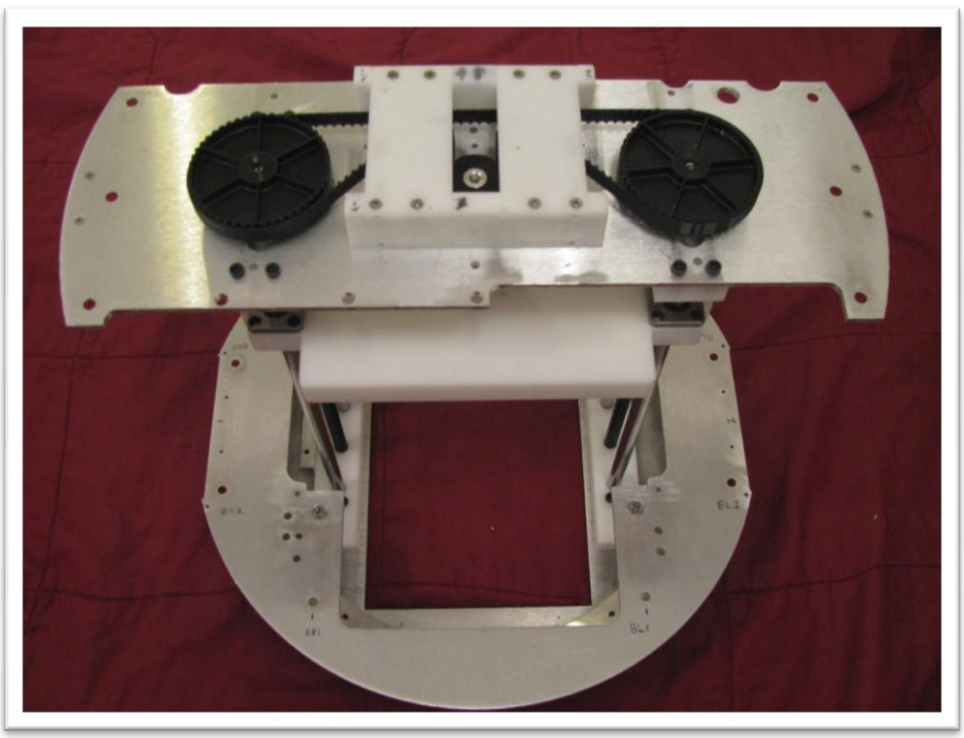

Figure 62: 2-3-2 Center foot mechanism top timing gears **- Photo by: Blake Mann**

Shoulder Rotation Mechanism:

When undergoing a 2-3-2 transition the body of the droid and the legs rotate to form a stable tripod stance. In a 2-3 transition the body of the droid rotates backwards while the outer legs rotate forward. The rotation is centered around the shoulder joint. The rotation is accomplished by two linear actuators that push on a lever arm that is attached to the shoulder rotation bearing. During the reverse 3-2 transition the same linear actuators pull on the shoulder lever arms to rotate the legs back into a vertical stance.

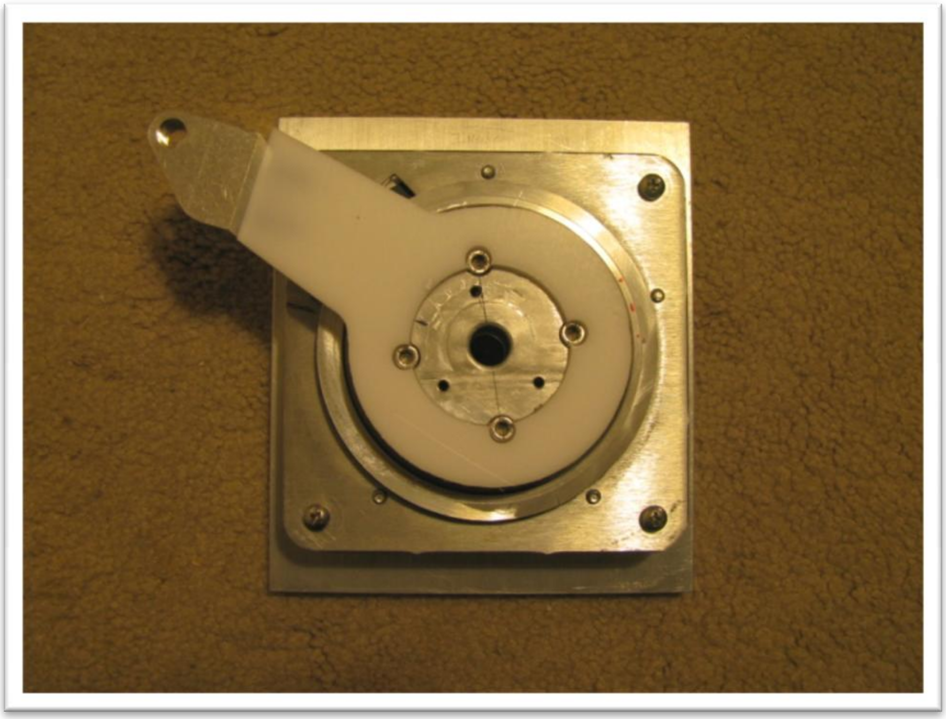

Figure 63: Shoulder lever mounted to shoulder bearing **- Photo by: Blake Mann**

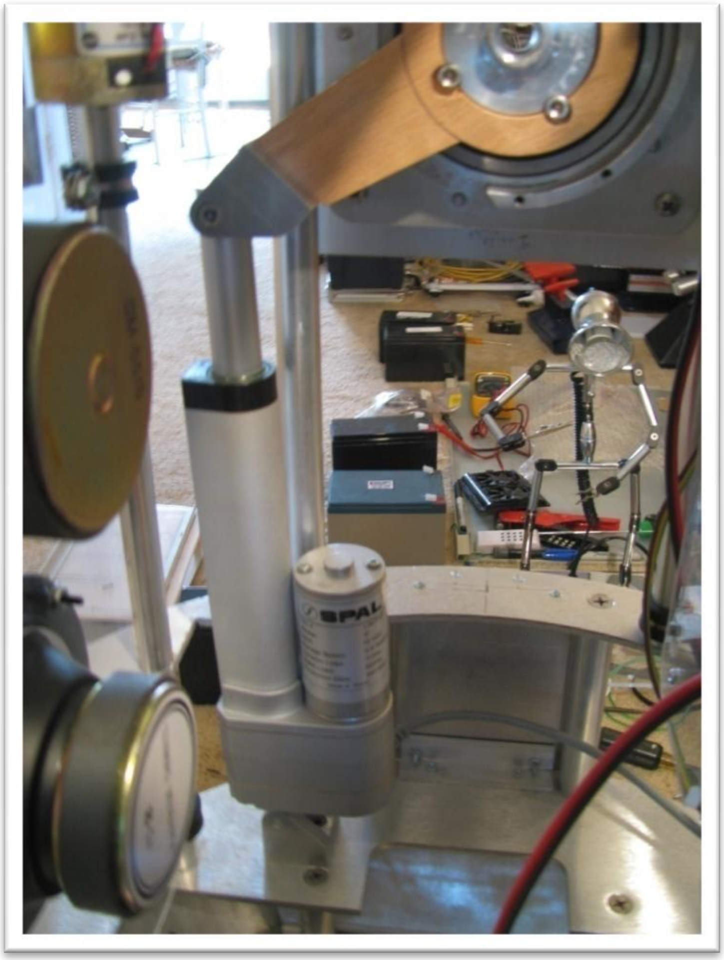

Figure 64: Prototype shoulder lever rotation by linear actuator **- Photo by: Blake Mann**

Ankle Joint Rotation:

In addition to the lifting and lowering of the center foot as well as the shoulder rotation the ankle joints of the droid also must rotate so that the foot drive units stay level with the surface. The ankle joints themselves are a free rotating joint. However, if they were allowed to rotate freely while the droid is standing upright the droid would fall either forward or backward. To prevent this an ankle pin mechanism is used to prevent movement of the ankle joint from rotating forward while the droid is standing upright. Since the ankle joint never has the need to rotate backwards a solid block is mounted between the top of the foot drive and the ankle joint preventing the ankle joints from rotating backward. While transitioning from 2-3 legs the ankle joint must rotate forward but it must rotate at the same angular rate as the shoulders are rotating. This is accomplished but retracting the ankle pin into the ankle with linear actuators mounted inside the legs. The get the necessary torque required to extend and retract the ankle pin the linear actuators inside the legs move a lever mechanism that in turn extends and retracts the ankle pin. Embedded micro processor software is used to make the whole 2-3-2 transition run smoothly by timing the movements of all 3 of these mechanical assemblies.

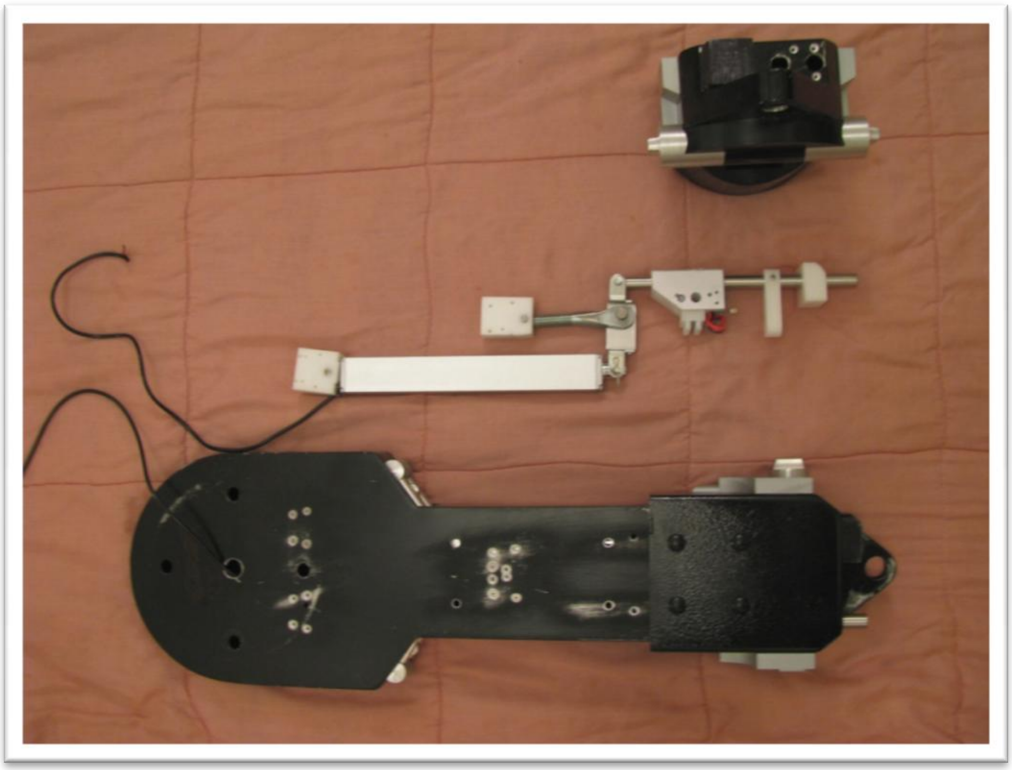

Figure 65: Ankle pin linear actuator **- Photo by: Blake Mann**

Other 2-3-2 Systems:

Many different 2-3-2 mechanisms have been developed for the R2 series droids. Some are like the R2-X2 system in that the three main motions are independently controlled while others use mechanical linkages to control ankle joint motion and shoulder rotation as linked movements. Some of the more successful 2-3-2 systems are as follows:

1. Mike Lambert 2-3-2 system:

    a. Controls the center foot lifting and lowering.

    b. Shoulder rotation mechanism: Satellite motors

c. Ankle Joint Motion: Leg rods linkages

2. Craig Smith:

   a. Center Foot Mechanism: Custom cable system.

   b. Shoulder rotation mechanism: Unknown

   c. Ankle Joint Motion: Leg rods

3. Bob Ross:

   a. Center Foot Mechanism: Custom double scissor linkage design.

   b. Shoulder rotation mechanism: Satellite motors.

   c. Ankle Joint Motion: Custom linear actuators mounted in the legs.

4. Cory Pacione:

   a. Center Foot Mechanism: Mike Lambert system hybrid, linear actuator replaces center satellite motor.

   b. Shoulder rotation mechanism: Linear actuators.

   c. Ankle Joint Motion: Leg rods

5. Daren Murrer:

   a. Center Foot Mechanism: Mike Lambert system hybrid – replaced nylon slides with linear bearings.

   b. Shoulder rotation mechanism: Satellite motors.

   c. Ankle Joint Motion: Leg rod linkages.

6. Peter Wishart:

   a. Center Foot Mechanism: Custom center leg lift – Motor & sprocket design.

   b. Shoulder rotation mechanism: Custom motor & sprocket design.

   c. Ankle Joint Motion: Unknown

7. Dave Painter:

   a. Center Foot Mechanism: Custom center leg lift – Lead screw design

   b. Shoulder rotation mechanism: Custom motor & worm gear design

c. Ankle Joint Motion: Leg rod linkages

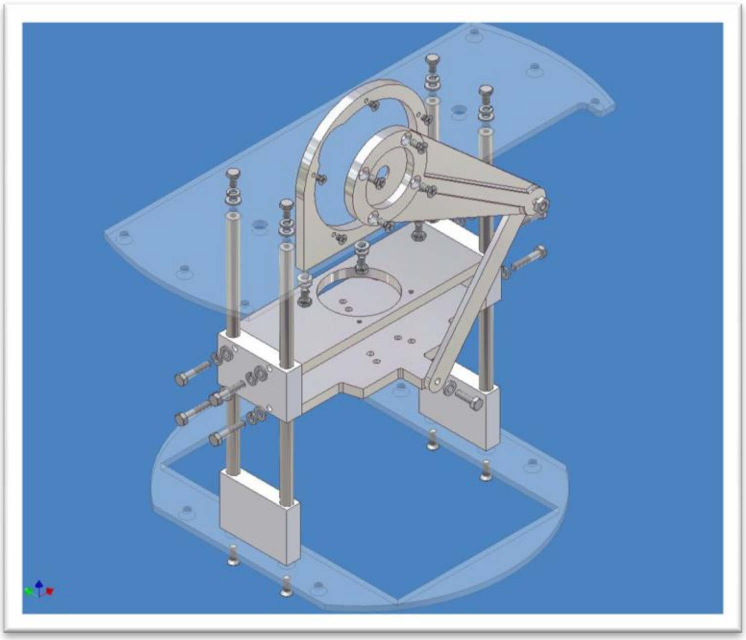

Figure 66: Center foot mechanism **- Mike Lambert**

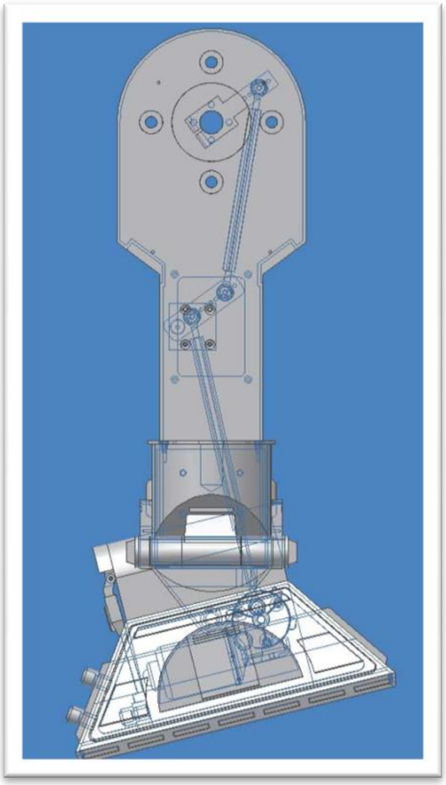

Figure 67: Ankle Rods **- Mike Lambert**

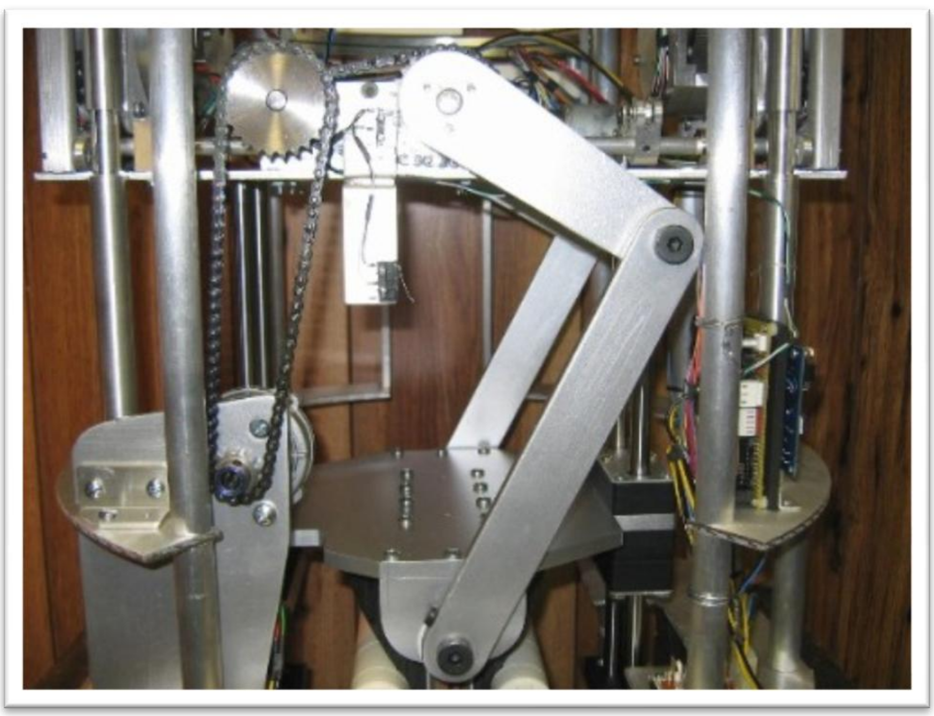

Figure 68: Center foot mechanism **- Photo by: Bob Ross**

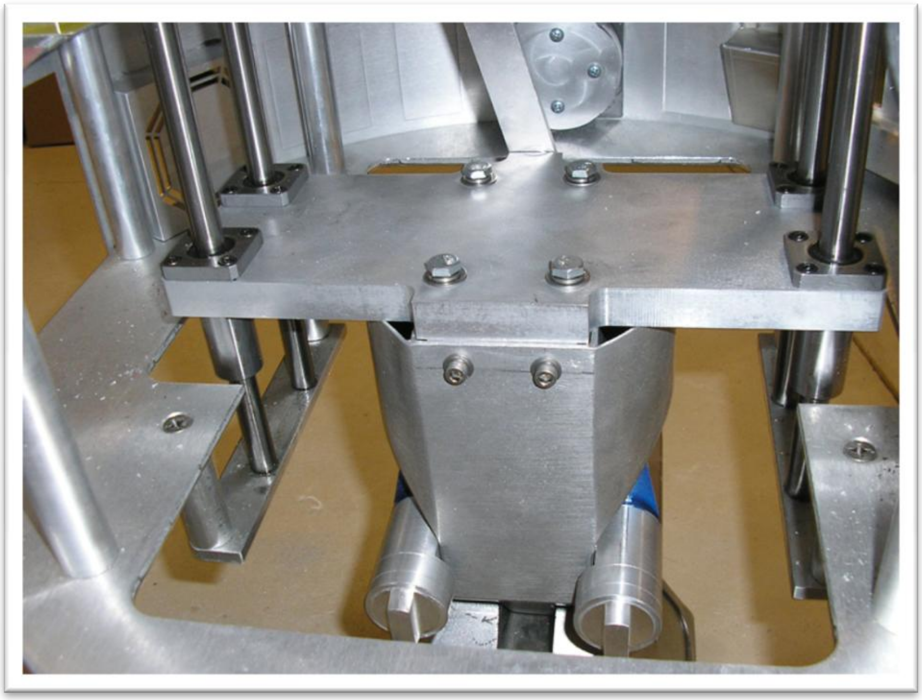

Figure 69: Center foot mechanism **- Photo by: Daren Murrer**

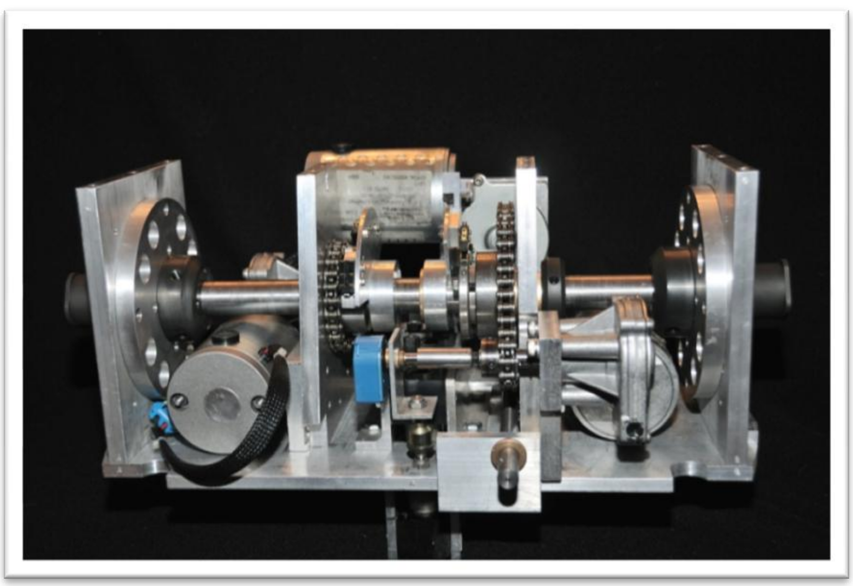

Figure 70: Center foot & shoulder rotation mechanism **- Photo by: Peter Wishart**

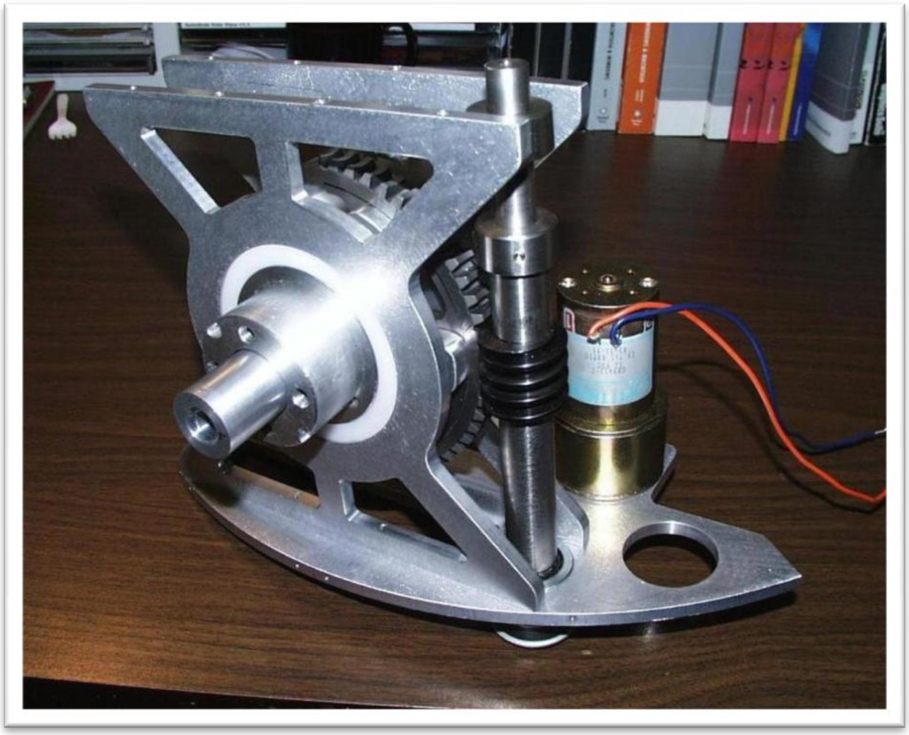

Figure 71: Shoulder rotation worm gear **- Photo by: Dave Painter**

Document written by: Blake Mann 2010