Project Sheet *WAVING HAND*

DESCRIPTION

The *WAVING HAND* is a simple electro mechanical project that consists of a Multi Ratio Gearbox, a linkage and battery.

SECTION 1: COMPONENTS & MATERIAL REQUIRED

1.1 COMPONENTS REQUIRED

The following components are required – it is suggested that you use this as a checklist to identify each component, and mark it off:

- ☐ 1 x Tube – Guide – 40mm (white) or Spacer (SPACER8 / GUIDW)
- ☐ 1 x Washer – 3mm inner – 1mm thick (WASH3X1)
- ☐ 1 x Washer – 3mm inner – 0.5mm thick (WASHER)
  Or 3 x Washer – 3mm inner – 0.5mm thick (WASHER)
- ☐ 2 x Pinion gear 12T – 2.4mm hole (GEAR12/2.4)
- ☐ 1 x Battery holder – 4AA *** (BH4AAF)
- ☐ 2 x Bolt M3x12 (BOLT12)
- ☐ 2 x Nylex Lock Nut M3 (NUTNYL)
- ☐ 1 x Electric Motor 3-12V (round) (MOT17)
- ☐ 1 x Screw – self-tapping – 2.6mm x 4mm (STSC2.6x4MM)
- ☐ 1 x Multi Ratio Gearbox kit (GMULTI)

** The project is specified with a 4 x AA battery holder, which allows for 6 volts. If a different voltage is required, a different battery holder will need to be purchased. NOTE: if using a 3 volt battery holder, the 2 AA battery holder is also available with a built in switch (BH2AAF) or without a switch (BH2AA). if using a 4.5 volt battery holder, the 3 AA battery holder is also available with a built in switch (BH3AAF) or without a switch (BH3AA). In either case, if getting the standard one, a separate switch (SSWS) is required.

1.2 ADDITIONAL REQUIREMENTS

The following items are required and are available from Scorpio Technology, but need to be ordered separately:

- ☐ 4 x Battery – AA (BATTAA or BATTALK)
- ☐ 2 x Self tapping Screws 4G x 6mm if a plywood base is used.
- ☐ Multi strand hook-up wire – in a variety of colours (WIREHU10)
- ☐ Hot glue (GLUEGUNMIN/GLUESTK7) or double-sided adhesive tape (TAPEDS)

NOTE: If a number of students are going to construct the *WAVING HAND* (i.e. as a class project), it is recommended that the class purchase a pack each of White (GEAR50/10/2.4) and Yellow (GEAR50/10/2.6-10) 50T gears. This is to enable the replacement of any damaged or lost parts that (inevitably) occur during student work.

The following material is to be supplied by the student / designer:

- ☐ Material for the base, linkage, arm and hand (For the prototype base 6mm plywood was used with 1.5mm plastic sheet for the linkage and arm / hand. 1mm HIPS or aluminium sheet would also be suitable etc.

1.3 TOOLS REQUIRED

The following tools are required. Several are available from Scorpio Technology, and can be ordered separately if required (item codes in brackets):

- ☐ Assorted hand tools and cutting tools – depending on the choice of materials to be used, such as:
  - Scroll saw or hand saw
  - Ruler / square and pen / marker
  - Scriber or pin punch
  - Sanding block and sandpaper
- ☐ Drill and Drill Bit:
  - 1.0mm drill (DB1.0)
  - 2.3mm (DB2.3) for???
  - 3.0mm for 3.0mm bolts
  - 6mm
- ☐ Small hammer (HAMMERCP)
- ☐ Tin Snips
- ☐ Soldering Iron: a good quality soldering iron, with a fine tip (SOLDIRN) and Soldering Iron Stand (SOLDIRNSTD) or Soldering Station (SOLDSTN)
- ☐ Solder: the use of 0.71mm 60/40 solder is recommended (SOLD250/SOLD500)
- ☐ Wire strippers (WIRESTR)
- ☐ Side cutters (SIDECUT or SIDECUTM)
- ☐ Mini Bolt Cutters (BOLTCUTM)

SECTION 2: GENERAL AND PLANNING INFORMATION

2.1 GENERAL

This project requires the student to design and build a *WAVING HAND*. This basic project is suitable to introduce students to Technology and Electrical work.

2.2 ITEMS FOR INVESTIGATION

To carry out this project, a student must:

- ☐ Evaluate the suitability of various materials, such as PVC, HIPS, acrylic or plywood. There is some information about the advantages and disadvantages of various materials on our website, under Technical info/Technology kits (https://www.scorpiotechnology.com.au/technology-kits)
- ☐ define the locations of components
- ☐ design and fabricate the base
- ☐ decide on the desired Gearbox ratio
- ☐ make and assemble the Waving Hand

SECTION 3: DESIGN

The major aspects of this project are the design, construction and assembly of the *WAVING HAND*. The design stage is crucial. At this stage the location of all the components is worked out. It is best to do this by laying all of the components on a sheet of graph paper or using a CAD program. The layout affects the minimum size and shape of the *WAVING HAND*'s base, as well as the ease of assembly.

3.1 CHOICE OF MATERIAL

For our prototype:

- 6 mm Plywood was used for the base. This material was chosen as it is easily cut, shaped, drilled and glued. Refer to Section 2.2 for information for using other materials.
- 1.5 mm plastic sheet was used for the linkage and arm. 1.5 mm plastic was used to make the prototypes hand.
    - 1mm Aluminium sheet could also be used for the linkages.
- A suitable picture of a hand was found on the internet, scaled to size, printed out and glued to material to be used for the hand and then cut, shaped and glued to the arm using hot glue.
    - Cardboard of suitable thickness could also be used and would probably be easier to cut to shape.

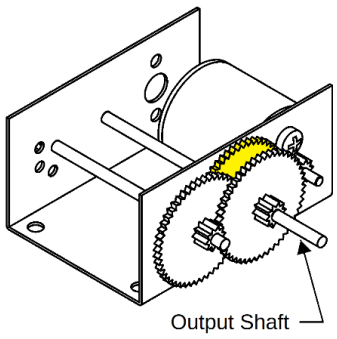
3.2 THE GEARBOX

This project uses a Multi Ratio Gearbox (*GMULTI*), A choice of 4 gearbox ratios is available and must be chosen prior to the base design.

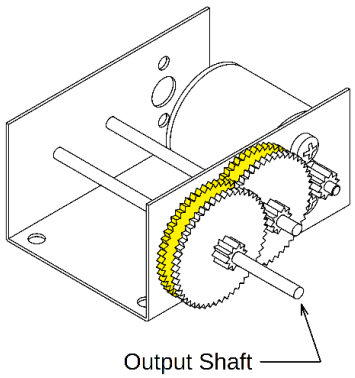
- The gearbox used for the prototype was the fourth reduction and uses the 4 x AA Battery Holder that provides 6 volts to the gearbox motor.
    - This produces about 1RPM at the output shaft.
- You can try using the Triple Reduction gear ratio and using a lower voltage battery to produce a lower output speed at the output shaft.
- Use the charts showing the information on the ratios for each version and the approximate motor speed for the different voltages shown.

NOTE: The choice of ratio affects which of the gearbox shafts will be the output (driving) shaft, that the gear and linkage are attached to.

The choice of ratios available at the "Output" shaft are:

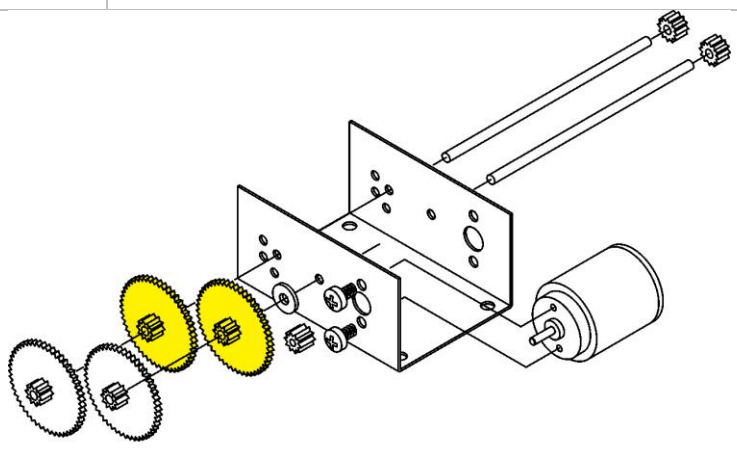


TRIPLE REDUCTION



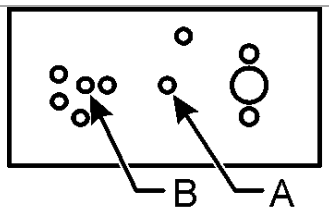
FOURTH REDUCTION

EXPLODED DIAGRAM OF THE FOURTH REDUCTION



- ✓ The motor turns at approximately 6,500 RPM under load, when using 3 Volts (2xAA batteries).

3.3 GEARBOX OPTIONS

GEARBOX STAGE / Reduction ratio	OUTPUT SHAFT	RATIO	
Triple reduction	Hole A	1:64	
Fourth Reduction	Hole B	1:228	

3.4 MOTOR OPTIONS

The Gearbox can be used with either the **MOT17** or the more powerful **MOT30** motor (MOT17 is suggested). The motor can operate between 1.5 and 6 volts.

3.4.1. STANDARD MOTOR (MOT17) - RATED AT 4.5V

Parameter	Performance
3 Volts: i.e. Powered by 2xAA batteries	6,500 rpm ##
6 Volts: i.e. Powered by 4xAA batteries	12,600 rpm ##
Torque	17.9 g.cm

Motor speeds quoted are approximate rpms under load.

3.5 LAYOUT

- ☐ Each student is able to, and should, design and build their own unique *WAVING HAND*. Before starting construction, the size and shape need to be developed on paper (or on a CAD program). However, the concept has scope for variation. Students should design a base to suit their own end usage.

3.6 OTHER DESIGN IDEAS

The drawings we used to illustrate this teaching unit, are of the *WAVING HAND* we made. It is up to each designer, to decide how different they want to make their own project.

SECTION 4: MAKING THE BASE

4.1 MATERIAL

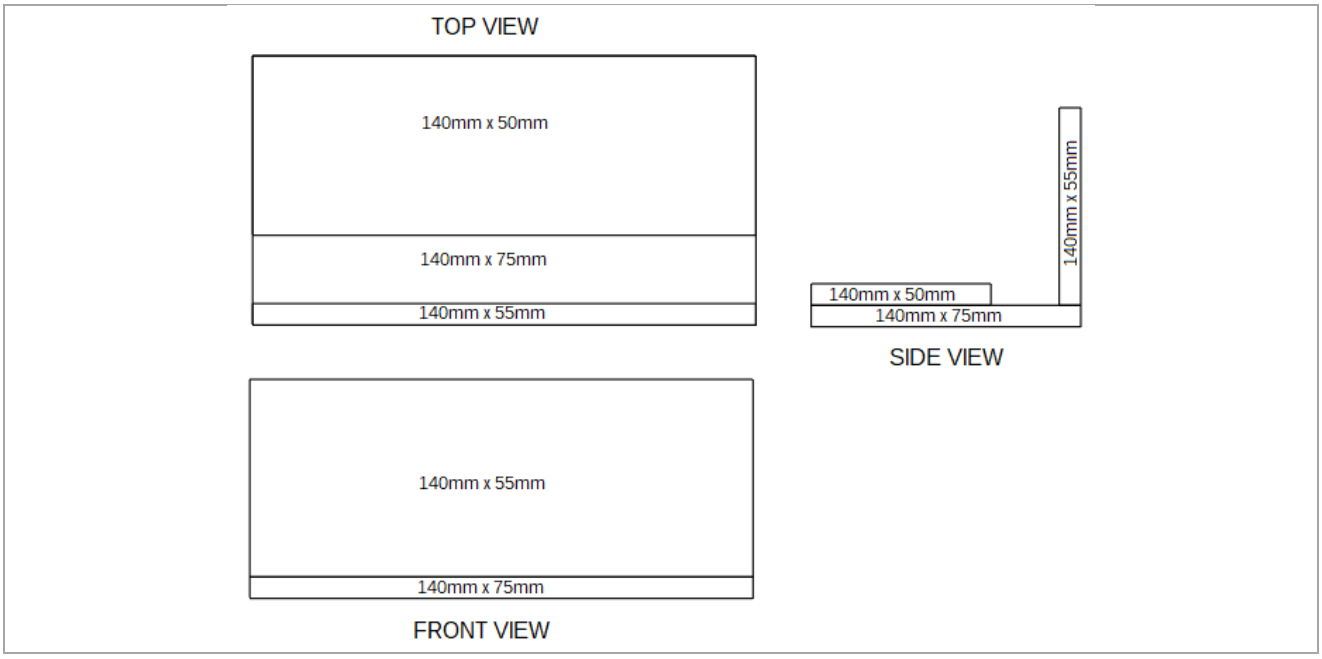
The base was constructed of 6 mm plywood. This material was chosen because it is relatively cheap, readily available and is easy to cut, drill and fix together.

You need to cut 3 pieces.

- ☐ 1 x 140mm x 75mm x 6mm
- ☐ 1 x 140mm x 55mm x 6mm
- ☐ 1 x 140mm x 50mm x 6mm

- ☐ Sand all 3 pieces clean and smooth.
- ☐ Apply wood glue to one side of the 50 x 140mm piece. Carefully place it down on top of the 140mm x 75mm piece and line it up along the back edge as shown below in the top and side views.

- Use a couple of large binder clips to hold the material firmly while the glue dries.



☐ After the glue has dried, mark a centre line 3mm in from the front edge of the 140mm x 75mm material.
☐ Next mark the line into about half a dozen equally spaced sections.
  - It is not important to measure these, it can be done by eye.
☐ If you have a drill, drill 1mm holes where the line is marked. If you cannot drill 1mm holes be very careful when you hammer in the nails that they are 90 degrees to the surface.
☐ Fix the 140mm x 55mm panel as shown in the side view.

SECTION 5: GEARBOX

5.1 THE GEARBOX

A choice of 2 gearbox ratios is available – you need to shorten the shaft that will not be used for the output shaft, and the motor needs to be assembled to the Gearbox:

- Refer below (5.2)

5.2 ASSEMBLING THE GEARBOX

Before starting assembly, the following must be done (based on the intended use of the gearbox):

☐ select the desired gearbox ratio – one of the two shown. The prototype used the Fourth Reduction and the battery holder used suits that Gearbox.

The following instructions detail how to assemble a *MULTI-RATIO GEARBOX V2*, using the MOT17 motor (the gears can be assembled onto the shaft/s with a help of small hammer).

NOTE: *For this Gearbox, the holes marked 'A' & 'B' in the drawings are to be used - the supplied gears will not function if fitted to any other holes.*

Before starting assembly:

- ☐ determine the desired gearbox ratio – this defines which shaft is the axle (output shaft).
- ☐ define the length of the axle shafts and cut (and de-burr) the steel rods to that length. Retain the cut off piece

NOTES:

- The 10T pinion gear (with a 1.9mm hole) is press fit on to the electric motor's 2.0mm shaft.

- ☐ The 12T pinions are used as locators.
- ☐ The white spur and 12T pinion gears (which have a 2.4mm hole) are press fit on to the 2.5mm shafts. The yellow spur gears have a 2.6 diameter hole and are freewheeling on the shaft.
- ☐ The outside two 50T spur gears (i.e. one on each shaft, furthest from the gear case) must be the white, press fit gears.

PREPARATION FOR ASSEMBLY

- ☐ Press the 10T pinion gear onto the motor shaft (using a small hammer).

HINT: Place the gear on the bench, insert the motor shaft into the pinion gear's hole and gently tap the end of the shaft (where it exits the motor) with a small hammer. Stop when the pinion gear is 1mm from the motor's body.

WARNING: Don't just push the motor down by hand as this can push the motor armature out of its bearings and jam the motor.

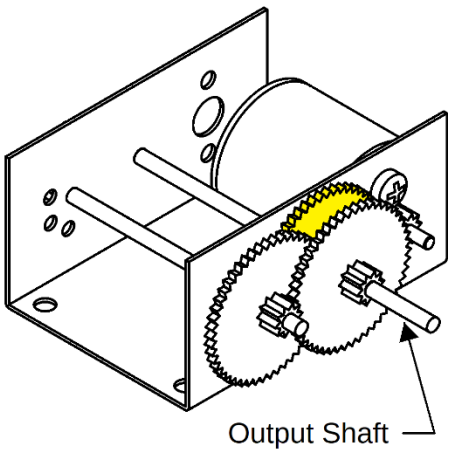
- ☐ Solder the wires from the battery holder wires to each of the motor's terminals – prior to installing the motor in the gear case.
  NOTE: Look at the terminals on the back of the motor. One of the terminals will have a + next to it. Solder the Positive (RED) wire to that terminal and then solder the Negative (BLACK) wire to the other terminal.
- ☐ Secure the motor to the gearbox case using the supplied two self-tapping screws.

5.2.1. TRIPLE REDUCTION

PARTS REQUIRED:

- ☐ *1 x Gear Case (Multi-ratio)*
- ☐ *2 x Shaft – Steel -2.5mm x 120mm*
- ☐ *2 x Pinion Gear 12T – 2.4mm hole*
- ☐ *2 x Spur Gear 50T/10T – white 2.4mm hole*
- ☐ *1 x Spur Gear 50T/10T – yellow 2.6mm hole*
- ☐ *1 x Washer – 3mm inner – 1mm thick*

- ☐ Start by fitting the first shaft to the hole nearest the motor (Hole A), add the 12T pinion gear (locator), with the 1.0mm washer between the case and one (yellow) 50T spur gear.
- ☐ Add the second shaft to Hole B and add the 12T pinion gear (locator) and one (white) 50T spur gear.



TRIPLE REDUCTION

☐ Install a (white) 50T spur gear on the shaft nearest the motor. For the THIRD reduction ratio, this shaft is the output shaft.

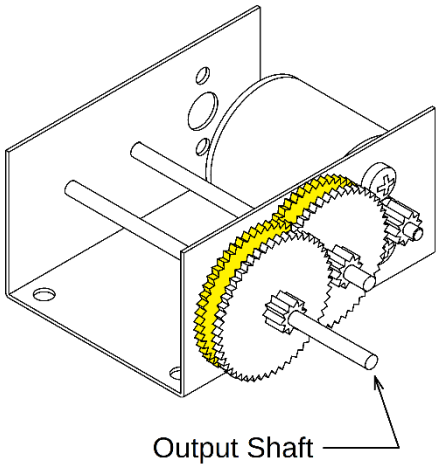
(High ratio = low output shaft speed)

5.2.2. FOURTH REDUCTION

PARTS REQUIRED:

☐ *1 x Gear Case (Multi-ratio)*
☐ *2 x Shaft – Steel -2.5mm x 120mm*
☐ *2 x Pinion Gear 12T – 2.4mm hole*
☐ *2 x Spur Gear 50T/10T – white 2.4mm hole*
☐ *2 x Spur Gear 50T/10T – yellow 2.6mm hole*
☐ *1 x Washer – 3mm inner – 1mm thick*

☐ Start by fitting the first shaft to the hole nearest the motor (Hole A), add the 12T pinion gear (locator), with the 1.0mm washer between the case and a (yellow) 50T spur gear.
☐ Add the 2nd shaft to Hole B and add the 12T pinion gear (locator) and the second (yellow) gear.
☐ Install a (white) 50T Spur gear on the shaft nearest the motor.
☐ Install the second (white) 50T Spur gear on the second shaft - for the FOURTH reduction ratio, this second shaft is the output shaft.



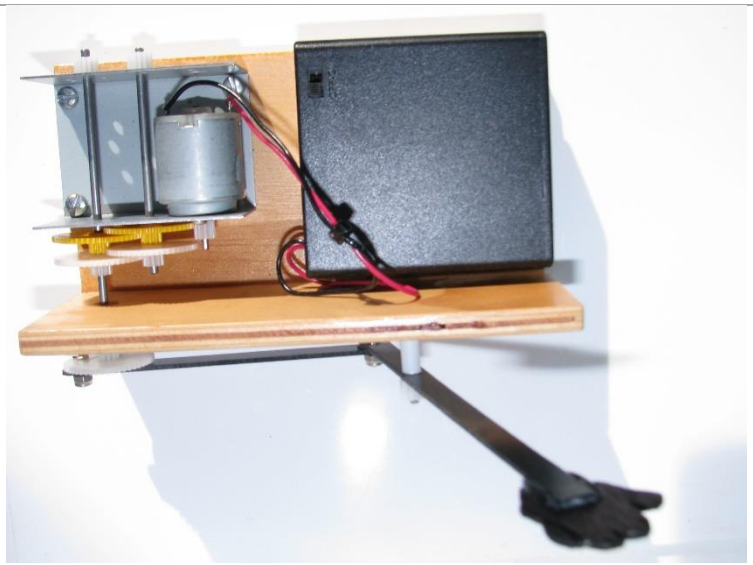
FOURTH REDUCTION

(High ratio = low Output speed)

SECTION 6: ASSEMBLING THE *WAVING HAND*

6.1 MOUNTING THE GEARBOX AND BATTERY HOLDER TO THE BASE

☐ Roughen up the bottom of the battery holder. Use either double sided tape or hot glue to fix the Battery Holder to the base.
☐ Place the assembled Gearbox at the left hand end of the base as shown.
☐ Press the long shaft against the front of the base so it leaves a mark in the wood. Drill a hole 6-8mm in dia. for the shaft to pass through.



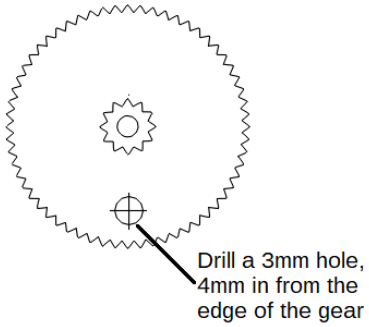
- ☐ Place the Gearbox onto the base as shown above and mark the positions for the mounting screws.
    - either use a brad awl or a small drill to create holes for the screws.

To hold the gearbox in place:

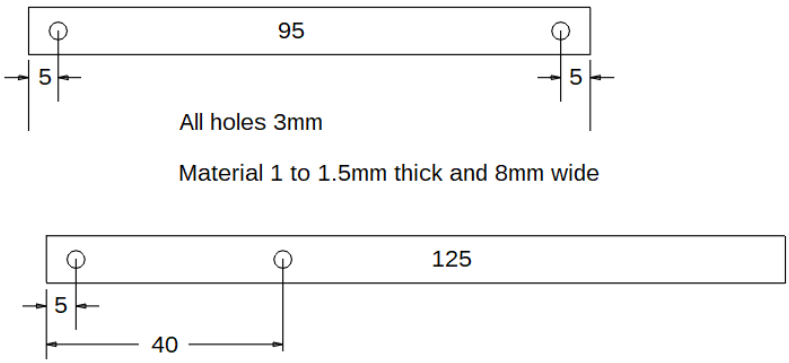
- ☐ Use 2 or 3 small screws to fix the Gearbox to the base as shown.
    - If only using 2 holes, make them the diagonally opposite holes in the gear case.
    - Make sure the screws are not long enough to pass through the base.
- ☐ You can also use 3mm bolts. If you choose to use 3mm bolts of a suitable length inserted from the top of the gear case and through the base, and a nut attached from below.
  NOTE: To allow the base to sit flat you will have to recess holes for the nuts so they do not protrude past the surface of the base.

6.2 MAKING THE CAM AND LINKAGES

- ☐ Mark the centre of a hole to be drilled, 4mm in from the outside edge of a White 50T gear.
- ☐ Create a centre hole mark for drilling using either a sharp scriber or very carefully use a centre punch.
    - Do not hit the centre punch too hard as the nylon gear can easily crack and break.
    - Once the hole has been marked carefully drill a 3mm hole in the gear. Drill slowly as the gear can easily be broken.



- ☐ Mark out an 8mm wide strip, 220mm long on some 1.5mm plastic sheet or 1mm aluminium sheet.
- ☐ Cut out the strip and then cut into two lengths, one 95mm (the linkage) and the other 125mm (the arm).



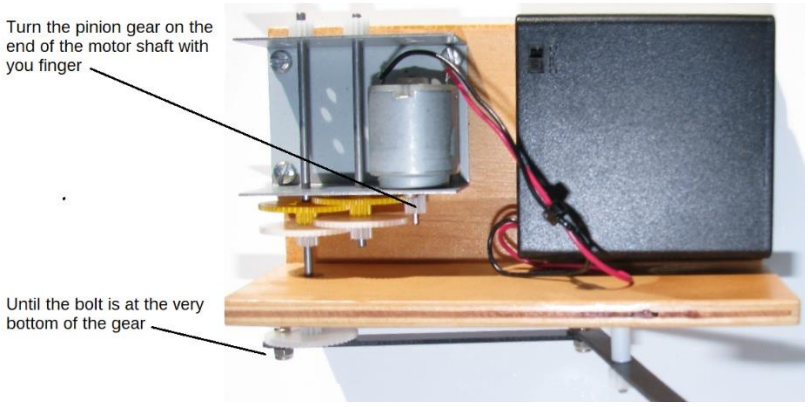
- ☐ On both ends of the 95mm length drill 3mm holes 5 mm in from each end. On the 125mm length drill a 3mm hole in 5mm from one end and from the same end mark and drill another 3mm hole 40mm in from the end as shown below.
- ☐ Draw your own hand, or search the internet for a picture of a hand.
    - Copy and scale it to an appropriate size.
    - Print out the hand, cut it out and glue it to a piece of thick (1.5 to 2mm) cardboard, plastic or plywood.
    - Carefully cut out the hand outline and then glue (hot glue works best) the hand to the end of the arm without any holes.

6.3 ASSEMBLING THE CAM AND LINKAGEs

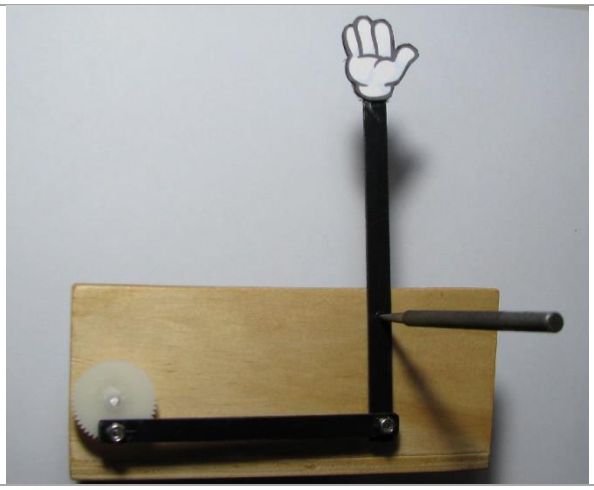
- ☐ Place the 50T gear that you previously drilled with a 3mm hole face down on a flat solid surface.
    - Make sure the pinion gear (12T) is facing upwards.

- ☐ Put the long shaft of the assembled Multi Ratio Gearbox into the centre hole of the gear.
- ☐ Use a small hammer and tap the other end of the shaft down into the gear until it is flush with the gear's surface.
    - You do not want the shaft to project past the gear or it will catch on the linkage and preventing the gearbox from turning.
- ☐ Insert an M3x12 bolt into one hole of the 95mm linkage.
- ☐ Place the thicker 3mm washer onto the bolt and then put the bolt through the hole in the 50T gear.
- ☐ Screw on an M3 Nylex Lock Nut onto the M3x12 bolt by hand.
- ☐ Holding the nut with a pair of pliers use a Phillips head screwdriver to do up the nut.
    - It should be done up very close but the linkage should still move freely.
- ☐ Place another M3x12 bolt into the hole at the other end of the linkage.
- ☐ Put the thin M3 washer onto the bolt and then insert the bolt into the hole at the end of the linkage with the hand. Screw an M3 Nylex Lock Nut onto the M3x12 bolt by hand.
- ☐

- ☐ Holding the nut with a pair of pliers use a Phillips head screwdriver to do up the nut. It should be done up very close but the linkage should still move freely.
- ☐ To mark the pivot point of the Waving Hand linkage, use your finger to move the pinion gear until the bolt attached to the gear is at the very bottom of the gear.



- ☐ Line up the linkage to the gear and waving hand linkage as shown below.
    - The gear should be turned so the bolt is at the bottom of the gear.
- ☐ Move the linkage so it is parallel to the bottom of the base.
- ☐ Move the waving hand linkage so it points straight up. Use a sharp brad awl or scriber and carefully mark the centre of the hole onto the front panel as shown opposite.



- ☐ Drill a 2.3mm hole about 4mm deep into the front panel at the point you marked earlier.
- ☐ Cut a 24mm length of steel rod and deburr one end (you can use the part you cut of the gearbox's shaft for this). Cut a 8-10mm length of plastic tubing, or use an 8mm Spacer.
- ☐ Make sure that the ends of the tubes are smooth and square (file or sand them).
- ☐ Place the front panel on a block of wood or on the edge of a bench or table (you may need someone to hold it in place for the next step.

- ☐ Place the end of the steel rod that hasn't been deburred into the 2.3mm hole.
- ☐ Carefully hammer the steel rod all the way into the hole. Place the length of white plastic tube or spacer onto the steel shaft.
- ☐ Put the steel shaft into the hole in the waving hand linkage.
- ☐ Place a 12T pinion gear onto the end of the steel shaft and tap it down until it is level with the end of the shaft.
    - You can use a second spacer or part of the white guide tube. Place it onto the 12T pinion gear and carefully tap the pinion gear down onto the steel tube. It should be very close but the linkage should still move freely.

SECTION 7: WIRING / ELECTRICAL COMPONENTS

7.1 ELECTRIC MOTOR

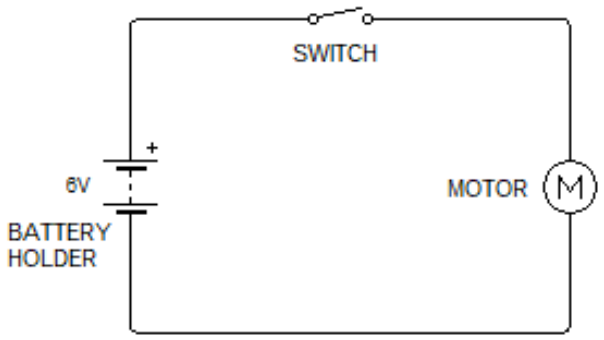
The electric motor is mounted as part of the Gearbox assembly.

- ☐ The project is specified with a 4 x AA battery holder, which allows for 6 volts.
- ☐ If a different voltage is required, a different battery holder will need to be purchased. Lower voltage gives slower speed, higher voltage means higher speed.
  WARNING: It is recommended not to increase the power supplied to more than 6 volts, otherwise the life expectancy of the motor may be significantly reduced.

- ☐ Solder the wires from the battery holder to each of the motor's terminals – prior to installing the motor in the gear case.
  NOTE: Look at the terminals on the back of the motor. One of the terminals will have a + next to it. Solder the Positive (RED) wire to that terminal and then solder the Negative (BLACK) wire to the other terminal.

7.2 THE TWO-WAY SWITCH AND BATTERY HOLDER

NOTE: If another type of battery holder is required a small slide switch will also be needed to turn the *WAVING HAND* on and off. The battery holder and switch are mounted on the base. The Switch should be wired as shown in the "Wiring Schematic".



WIRING SCHEMATIC

SECTION 8: THEORY – GEARS AND GEAR RATIOS

Gears transfer rotary motion from one gear to another by contact between their teeth.

There are 3 reasons why gears are used.

- To change the speed of rotation (this can be either an increase or decrease in speed). This is called the Velocity Ratio (VR).
- To change the applied force (this can be either an increase or decrease in the applied force). This is called the Mechanical Advantage (MA).
- To change the direction of rotation (meshing gears always turn in opposite directions).

DRIVER AND DRIVEN GEARS

When gears mesh, one gears makes the other gear turn. The gear that causes the turning is called the DRIVER Gear. The gear that is turned is called the DRIVEN Gear.

The gear connected to the end of a motor shaft is called the DRIVER Gear.

The first picture shows two gears meshing. The 10 Tooth gear turns the 50 Tooth gear.

The 10 Tooth gear is the DRIVER Gear.

The 50 Tooth gear is the DRIVEN Gear.

If you imagine that the 10 Tooth gear is connected to the end of a motor shaft then the force supplied by the motor will be through the 10 Tooth gear. When the 10 Tooth gear turns once, its 10 teeth will mesh with 10 teeth on the 50 Tooth gear. The 10 Tooth Driver gear will have to make 5 completed revolutions to mesh with the 50 teeth on Driven gear, causing it to turn once.

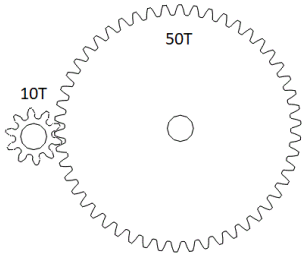
The number of times each gears turns is called the **V**ELOCITY **R**ATIO

If the number of teeth on both gears are known then their Velocity Ratio can be calculated.

$$\text{Velocity Ratio} = \frac{\text{Number of Teeth on Driven Gear}}{\text{Number of Teeth on Driven Gear}}$$

$$= \frac{50}{10}$$

$$= 5$$

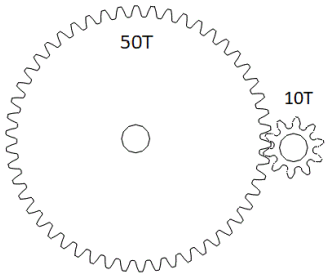


- The Velocity Ratio is 5. The driver gear must turn 5 times to make the driven gear turn once.
- The Mechanical Advantage will also be 5. The force applied by the driver gear will give the driven 5 times the force (turning power).

$$\text{Velocity Ratio} = \frac{\text{Number of Teeth on Driven Gear}}{\text{Number of Teeth on Driven Gear}}$$

$$= \frac{10}{50}$$

$$= 0.2$$



The Velocity Ratio is 0.2. The driver gear turns once causing the driven gear to turn 5 times. The Mechanical Advantage will also be 0.2. The force applied by the driver gear will give the driven gear 0.2 times (one fifth) of the force (turning power).

- If you decrease speed using gears you will increase the turning force.
- If you increase speed using gears you will decrease the turning force.

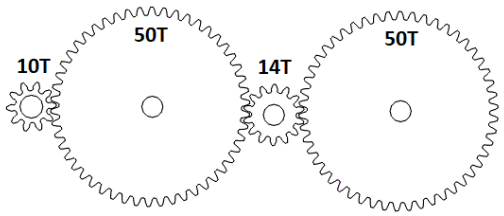
GEAR TRAINS

A gear train is a combination of two or more gears that transmit turning force from the input gear to the output gear.

The two pictures shown are the same gear train just shown differently.

In both cases the driver gear is 10 Tooth gear on the left.

This shows the 4 gears meshing. The 10 Tooth gear is a driver gear. The 50 Tooth gear meshing with it is the driven gear. The 14 Tooth gear is a second driver gear and the 50 tooth gear meshing with is a second driven gear.



This is set of gears works identically to the one shown above. This type of gear train is called a Compound Gear Train. In this case the 14 Tooth gear is attached to the 50 tooth gear. Its advantage is that many gears can be mounted together in a much smaller space.

The method of calculating the Velocity Ratio (VR) and Mechanical Advantage (MA) are identical

Velocity Ratio = VR

$$VR = \frac{\text{Product of the number of teeth on the Driven Gears}}{\text{Product of the number of teeth on the Driver Gears}}$$

$$= \frac{50 \times 50}{10 \times 14}$$

$$= \frac{2500}{140}$$

$$= 17.86 \text{ or } 18$$