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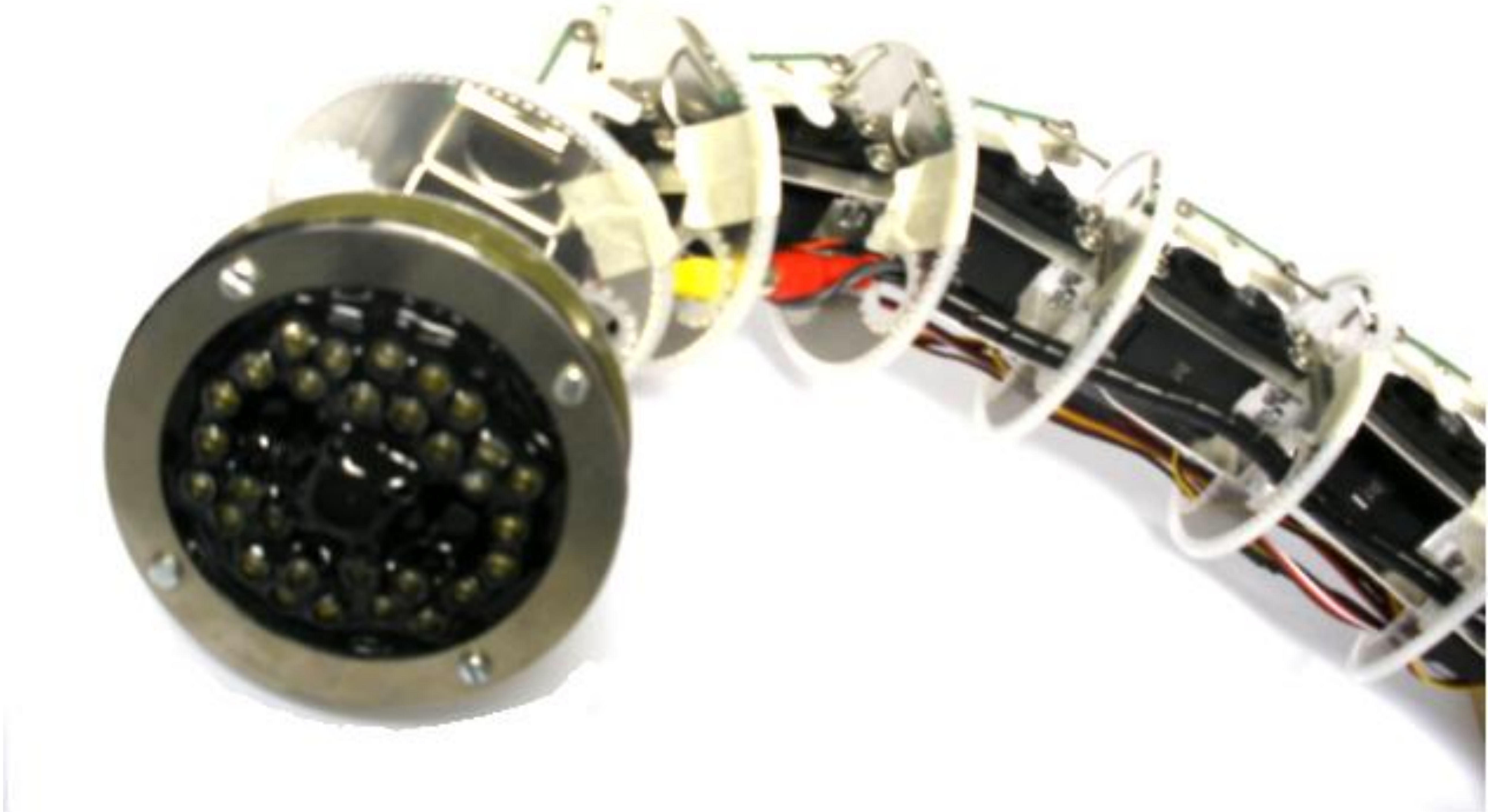

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Analysis of Problem

Situation

Robots were first created in very basic forms for factories to speed up production. Robots were noted for the ability to work non-stop and work with the same accuracy and precision for hours on end. There were suited to repetitive labor, where humans would tire or reduce their quality output.

However robot arms have been stuck on a basic form of rigid lengths with joints either side. This is because they are large and are created for a specific job. However as robotics evolve; scientists are turning to robots for all types of jobs ranging from mars exploration to performing surgery. Robot designs are no longer confined to the standard designs; they are being designed to be flexible and versatile. I intend to join the many organisations that are developing robotic technologies.

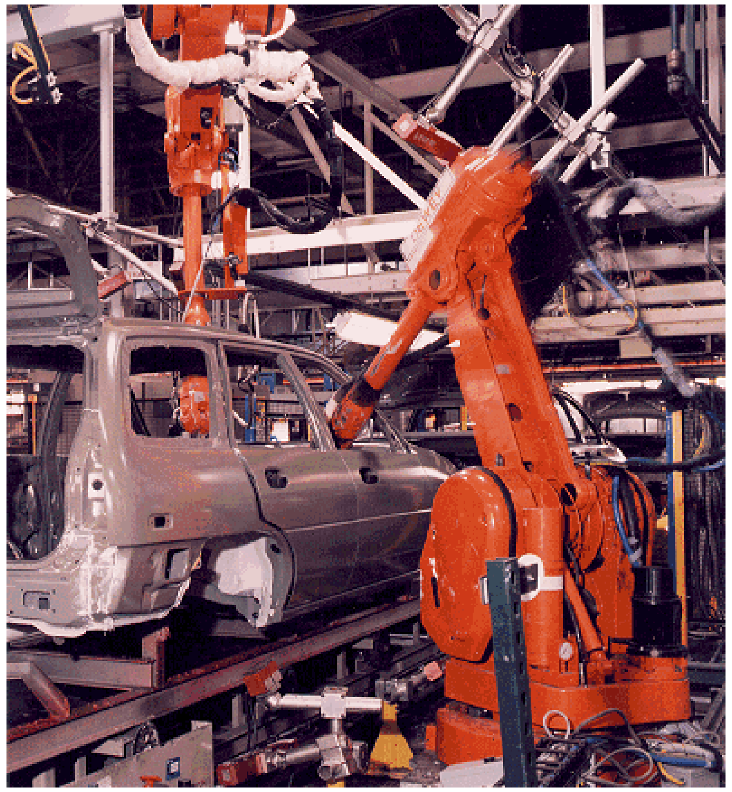
Project Brief

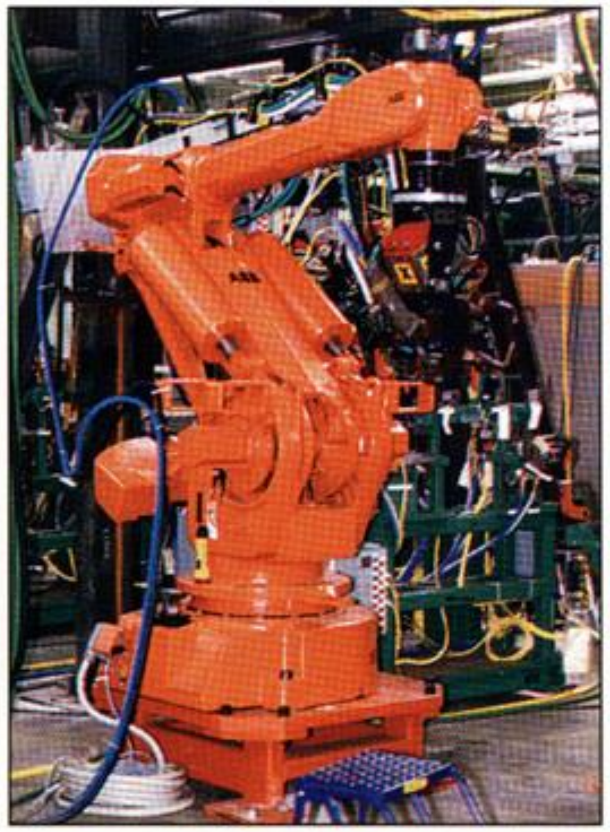
Robotics is a very large part of engineering, and in some respects is a whole subject on its own.

I am concerned about robotic arms in particular for my project, and I want to create a new type of robotic arm which is versatile and cheap.

Initial Specification

- The robot arm must be different from all standard designs.
- The arm must be safe to use and be around.
- The arm needs to be relatively simple to use.
- The arm needs to be capable of providing useful feedback to the user.
- The arm must be highly versatile.
- The arm needs to be small.
- The arm must be cheap to buy and have low maintenance.
- The arm must use a reasonable amount of power.

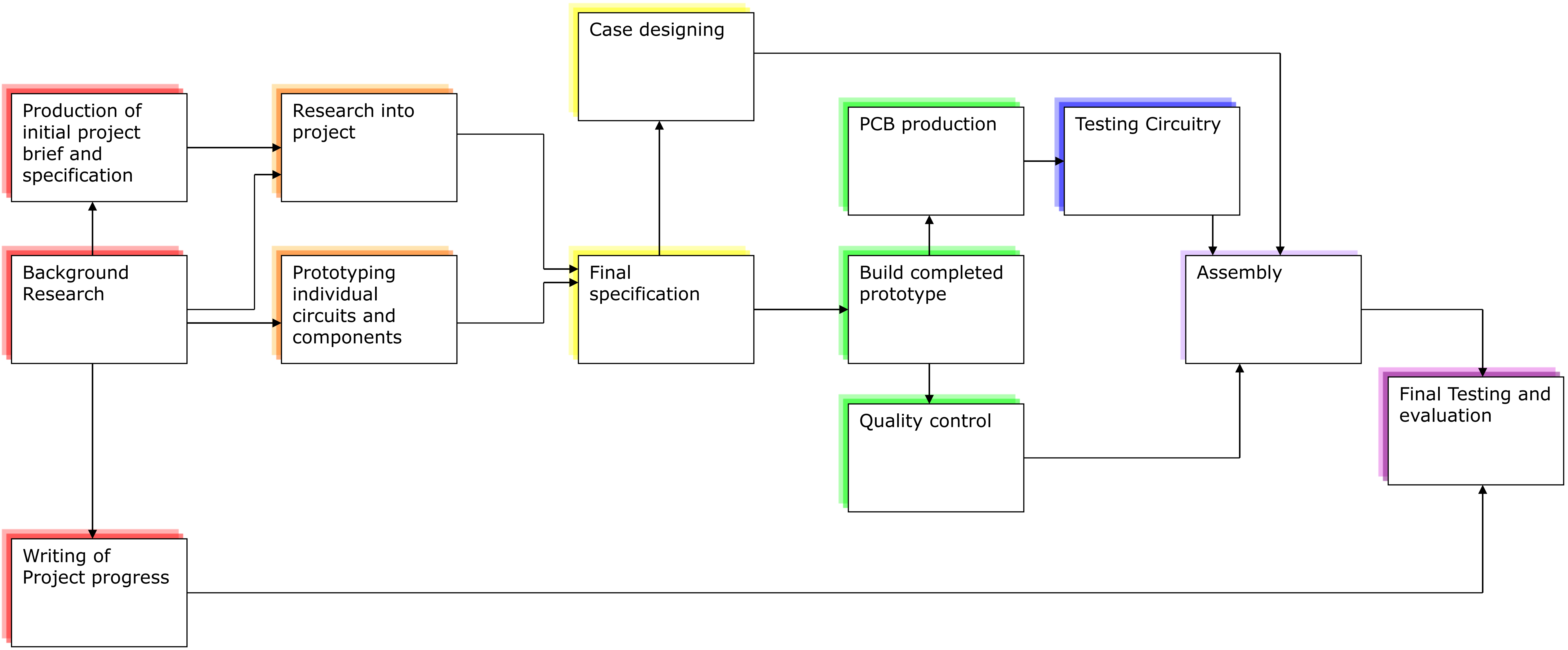


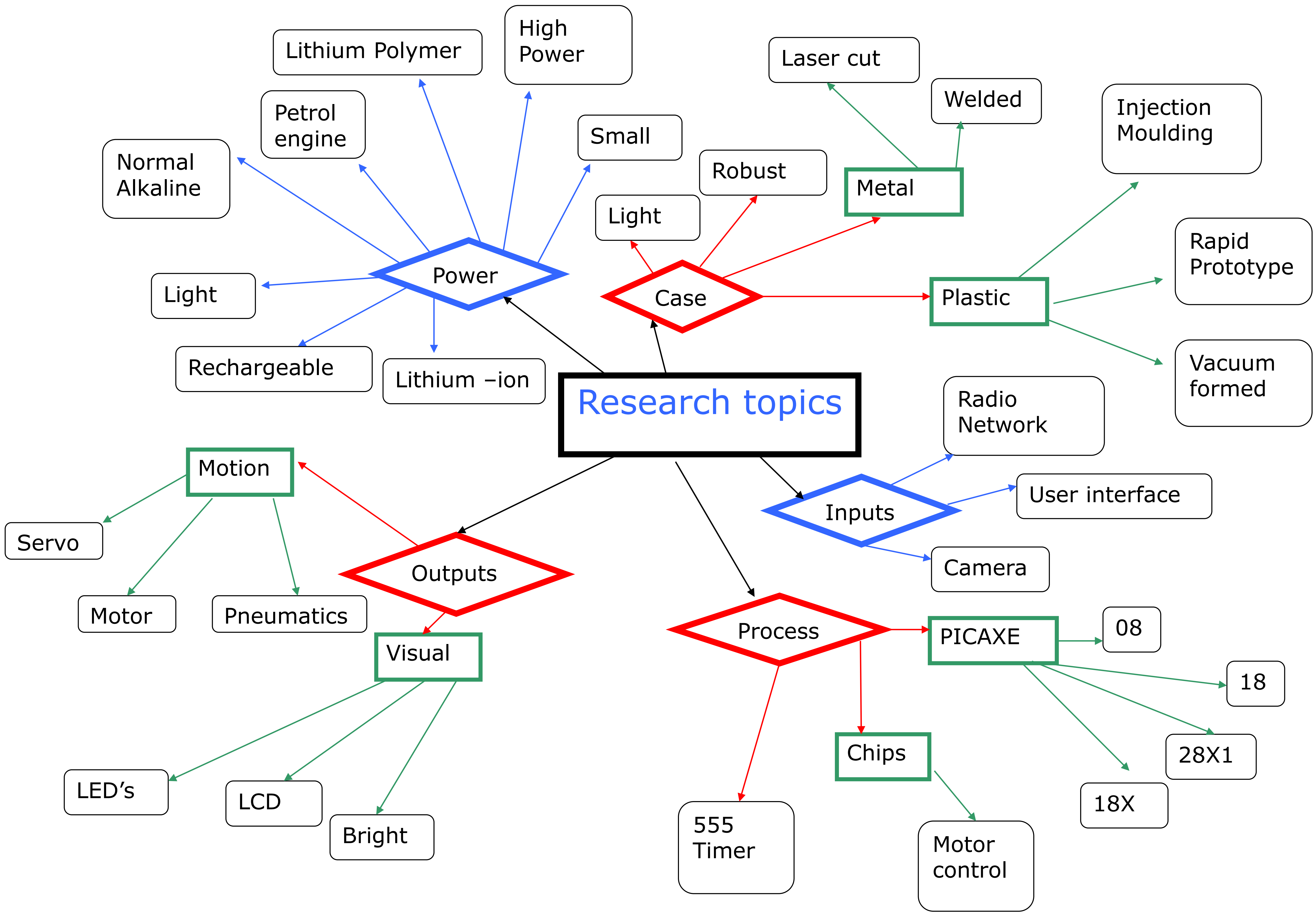


Assembly robots in a car factory

Pert chart

I have produced this pert chart as a guide to the path I will take on this project




Research topics
Power
Lithium Polymer
High Power
Petrol engine
Normal Alkaline
Small
Light
Rechargeable
Lithium –ion
Case
Light
Robust
Laser cut
Welded
Metal
Injection Moulding
Plastic
Rapid Prototype
Vacuum formed
Inputs
Radio Network
User interface
Camera
Outputs
Motion
Servo
Motor
Pneumatics
Visual
LED's
LCD
Bright
Process
PICAXE
08
18
28X1
18X
Chips
Motor control
555 Timer

Research Power

Alkaline

Alkaline batteries have been available for a very long time now; they are a good, cheap, reliable source of power. They are available in a range of sizes to suit my project.
Also available are high power alkaline batteries, such as Duracell's "M3" range. They have high capacity and are advertises as leading the class in duration

Lithium ion

Lithium ion batteries are the latest in battery technology; they are compact, light and offer high power outputs. They can also be recharged. Lithium ion batteries are already being used in high drain products such as digital cameras and mp3 players. Now they are widely available in most electronics stores, however they are more expensive than other batteries.

Engine power

In the same way as cars, their power is developed via their engine. The electricity comes via an alternator connected to the engine. With recent model technology there are now available small nitro engines. These have been used by modelers for years in their RC cars boats and planes and can propel their cars up to 60mph. These engines do not lack power. I propose that rather than use it for direct drive and power, that I hook it up to a generator to power all the electrics plus electric motors. This is a good set up because the engines are small and very powerful, this means that they can produce the electricity on demand when there is a high output needed.

Rechargeable

Rechargeable batteries have been around for quite a while now. They can be used in anything; they are good for their economy and are available at a reasonable price. However their power outputs aren't as high as the Lithium ion batteries.
But now new kinds of rechargeable battery are available called "Rechargeable Advanced", their power output is very close to the Lithium ion batteries. They are now also being used in high drain devices, because they can be reused for over 1000 charges. Also improved charges are now boasting charge times of 80minutes. Also they are available in many different shapes and sizes. Rechargeable batteries lose 1% of their power per day if not used. They are suited to being used almost constantly (i.e. devices that are constantly on).

Lithium Polymer

These are the next step after lithium ion. Also from the modeling world, loved by modelers because of their light weight and incredible power output, some being able to output a constant 30A for 20 minutes.

However they are extremely temperamental. They need to be charged very carefully with a special charger. They can not be discharged below a voltage or they could be damaged. Also if discharged too fast then it could swell and explode. The batteries are susceptible to combust if not used correctly. As a result they are expensive. But if used properly the value is worth it as it will consistently deliver power for a long time.

Conclusions

Power sources and batteries especially have been developed enormously over the past 10 years. New power technologies like lithium-ion and lithium polymer batteries were developed and improvements to existing systems such as alkaline batteries. The engine idea is very interesting and has real potential for "on demand" power delivery.

The only power source I can exclude now are the alkaline batteries, the power demands of my project would mean regularly replacing the batteries which could be expensive. All of the other batteries listed above would be suitable, but the final decision will depend on the direction I go with the case design later on the project. Also the engine idea needs serious consideration, if chosen it would be a totally new idea and it would need my time to develop it and make it work. So perhaps it would not be wise to be developing a new power system in addition to the project.

Wireless communications

Bluetooth and Zigbee

Bluetooth and Zigbee are both forms of short range radio based systems. They were both designed to create a free short range network for electronic devices to communicate with each other. The better established version is Bluetooth which has been around for a few years now and is used in a wide range of application such as wireless keyboards and data transfer between mobile phones. Zigbee is a newer arrival and was developed by a coalition of companies who wanted to also create a free short range network between electronic devices. The advantage of Zigbee over Bluetooth is that it uses less power and also is smaller in size.

LINKMATIK Bluetooth module

Zigbee

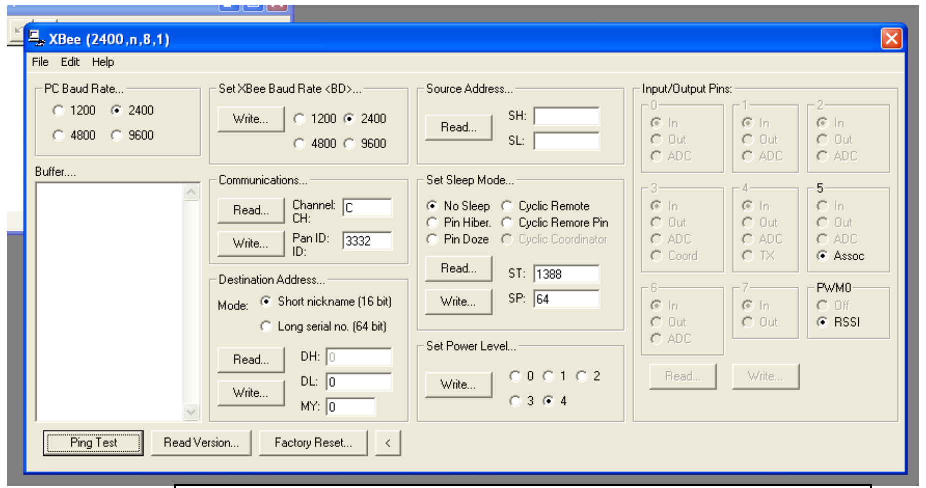
On device that provides Zigbee communication is the Xbee radio module by Maxstream. It operates a 2.4 GHz frequency and the pro version has a range of 100m. The Xbee can be programmed through a serial interface circuit by a computer. It is compatible with the popular microprocessor series PICAXE, this allows a wide verity of functions to be preformed with it.

The Xbee module is very easy to use especially in conjunction with a PICAXE system. The Xbee can be programmed with its own number for identification allowing it to select which messages are intended for it, in a similar way to Ethernet.

Bluetooth

Bluetooth modules are available to buy one such model by LINKMATIK. It has a fast data rate of 50Kbits/s and a large range of 100m. It is self running and needs no commands to run; it can pair up with other Bluetooth devices such as PDA’s or mobile phones. It has data encryption and PIN for secure data transfer.

However it is significantly more expensive that the Xbee system.



Screenshot of the Xbee wizard

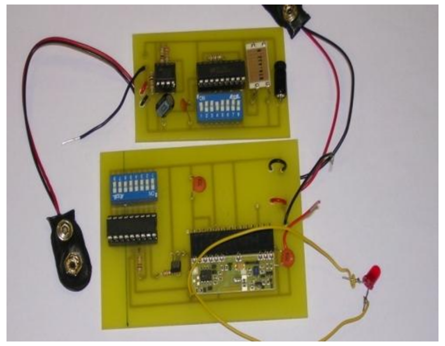
This is the Xbee starter development pack from Revolution education one of the PICAXE system suppliers. This kit provides everything for a total novice to learn and understand how to use the Xbee system. It’s coupled with the PICAXE system providing basic demonstrations of the use and functionality of the system.

The PICAXE program compiler also has an “Xbee wizard” function which allows the settings of the Xbee itself to be set easily.

Xbee development kit.

AM and FM

To the right is an AM transmitter and receiver, this transmitter has a range of 50 meters, which a good distance. The signals can also be coded, that gives me many different signal combinations which I can use to control different things, such as the outputs. There is also an FM radio available. This is a lot simpler than the Xbee and Linkmatik and it has a very low data transfer rate and it would not be suited to carry a lot of information.



Conclusions

The simpler AM and FM radios are cheap, very easy to use and I have worked with them in previous projects. However for this application they are out of their league, they have a very small data transfer capability and do not integrate well with any type of processor.

The Xbee and Bluetooth options are more appealing they have an impressive data transfer rate and they both would be compatible with a PICAXE processor. The Xbee has the upper hand though it is considerably less expensive than a Bluetooth system and defiantly easier to integrate, thanks to the PICAXE system.

Processing

In any system information and data is being transferred and translated and outputted. It is the job of the processing unit to handle the responsibility of making sure everything is doing what it is supposed to, orchestrating the whole system.

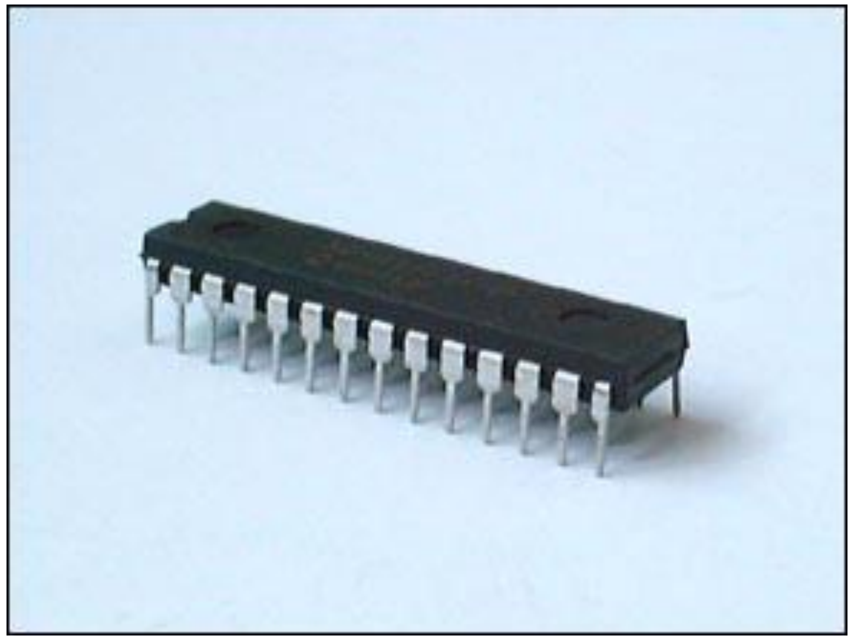
In my project there is potential for a lot of complex operation and multiple devices working together. The processor that could control all of this is a PICAXE. The PICAXE system was first released by revolution education, during the microchip revolution. This is a type of microcontroller, currently well established in industry it replaces the traditional CMOS and TTL integrated circuits like logic gates.

Microcontrollers are new electronic 'single chip computers' that are rapidly being introduced into industry and education. The 'PICAXE' system is an extremely powerful, yet low cost, microcontroller programming system, and it is very easy to use and understand.

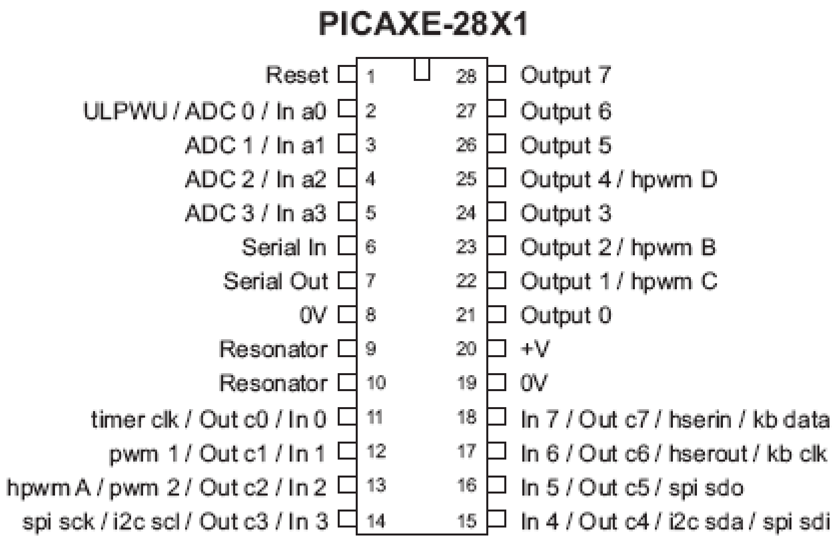
The PICAXE is designed to bring microcontrollers into education; they are very easy to use and easy to understand. They demonstrate a very wide rage of operations; they have onboard memory which can be programmed via the free programming software and come in four sizes. Their specifications are shown in the table below. PICAXE have recently released new X1 and X2 version of the 28 and 40 chips. These have a very large memory and USB connectivity among other improvements.

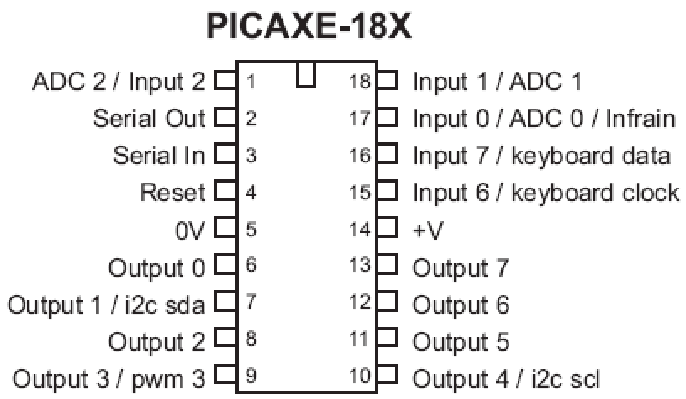
PICAXE Type	IC Size	Memory (lines)	I/O Pins	Outputs	Inputs	ADC (L =low)	Data Memory	Polled Interrupt
PICAXE-08	8	40	5	1-4	1-4	1L	128 - prog	-
PICAXE-08M	8	80	5	1-4	1-4	3	256 - prog	Yes
PICAXE-18	18	40	13	8	5	3L	128 - prog	-
PICAXE-18A	18	80	13	8	5	3	256	Yes
PICAXE-18X	18	600	14	9	5	3	256 + i2c	Yes
PICAXE-28A	28	80	20	8	8	4	64 + 256	Yes
PICAXE-28X	28	600	21	9-17	0-12	0-4	128 + i2c	Yes
PICAXE-40X	40	600	32	9-17	8-20	3-7	128 + i2c	Yes

A 28X1 Chip



18X and 28X1 Pinouts





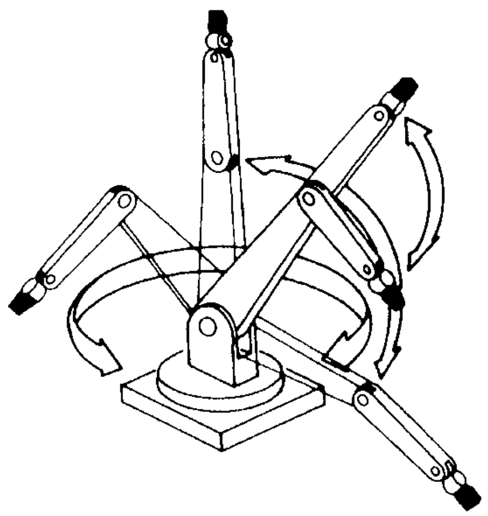
Conclusions

The PICAXE system is very impressive. Relatively new in the microprocessor world it has so much to offer. It has a lot of features and is extremely easy to use and understand. The serial data capability is very appealing and would make IC's communicating with each other very easy.

Research Robot Motion

The joints in your arm, and your ability to move them, are called degrees of freedom. Your shoulder provides three degrees of freedom in itself; shoulder rotation and two plane shoulder flexion. The elbow adds a fourth and fifth degree of freedom: elbow flexion and rotation. Robotic arms also have degrees of freedom. Bus instead of muscles, tendons joints and bones, robot arms are made from metal, plastic, motors, gears and other mechanical components.

Robot arms are classed by the shape of the area that the end of the arm can reach. This accessible area is called the work envelope.
The human arm has a nearly spherical work envelope. It can reach anything in arms length, within the inside ¾ of a sphere. In robotics, such an arm would be said to have revolute coordinates. The other types of arm are polar, cylindrical and Cartesian coordinate.

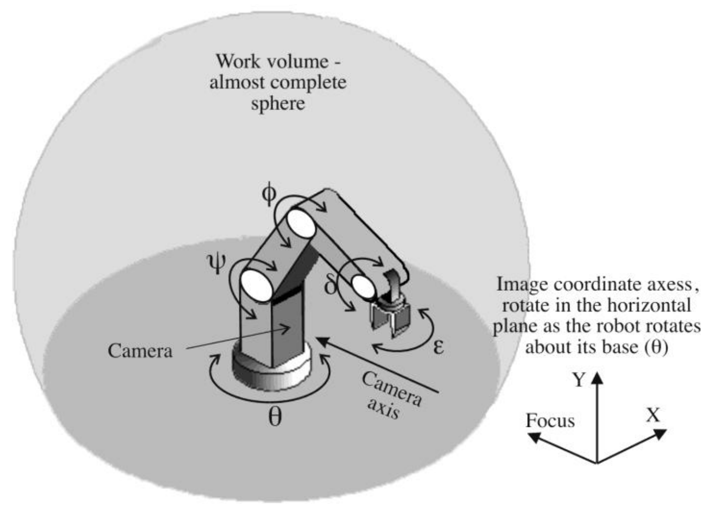


Revolute coordinate arm

Revolute coordinate

Revolute coordinate arms are modeled after a human arm, so they have many of the same capabilities. The design is somewhat different due to the complexity of the human shoulder joint.
A robotic shoulder joint is usually two different mechanisms. Shoulder rotation is achieved by rotating the whole arm at its base. Shoulder flex is achieved by tilting the upper arm section backwards and forwards. Elbow flex works in the same way as a human with a hinge joint moving the forearm up and down. Revolute arms are favored due to their mobility because of their similarity to a human arm. They are also suited to many applications, whereas the other designs are built for a certain purpose.

Work envelope of a revolute coordinate arm, same as human arm.



In addition to trying to mimic movements in nature in robotics, there are some types of motion that are not found in nature and are purely mechanical such as rolling on tracks or extending an attachment.

This is an example of a revolute coordinate arm, which is mimicking natural movement. However it can move in a track which is an unnatural movement.

This is a prosthetic human arm. In prosthetics they try to mimic natural movements totally. This arm hasn't got quite the same joints as in a human arm, but is does have the same range of movement and will function exactly the same as a human arm.

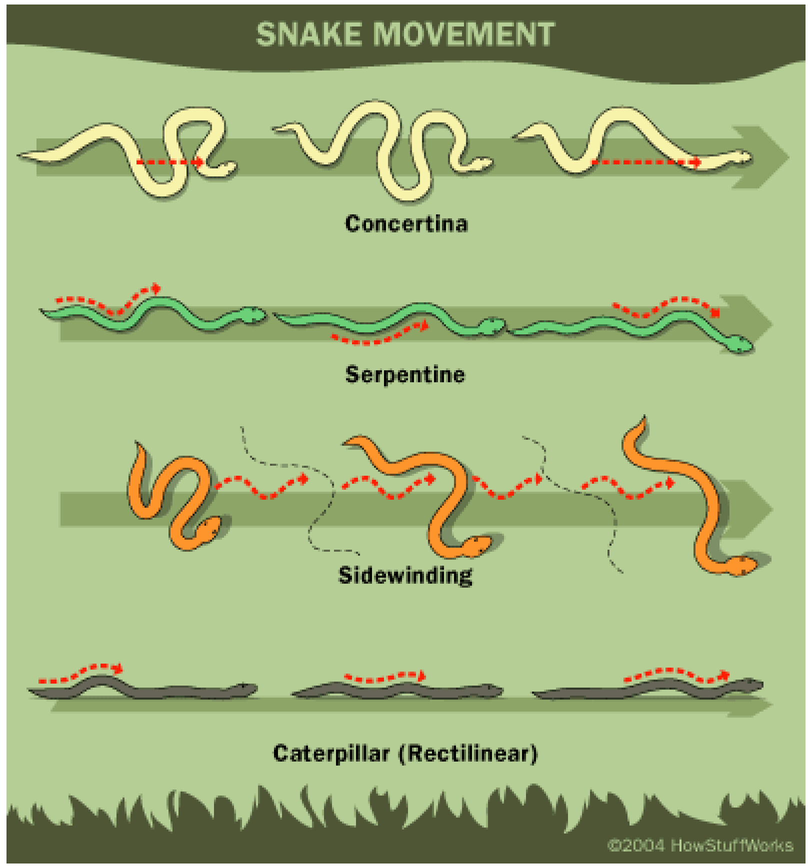
Conclusions

In robotics there are both natural and unnatural movements. The decision on which to use will depend on what the intended use is. If it's just for maximum maneuverability then any method will be considered to make the most maneuverable arm.

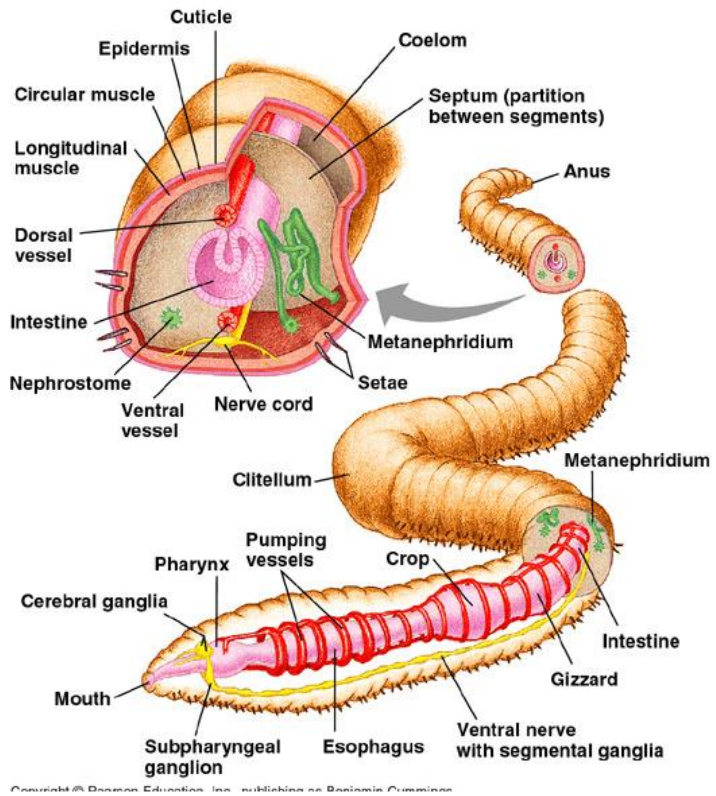
Research Animal Motion

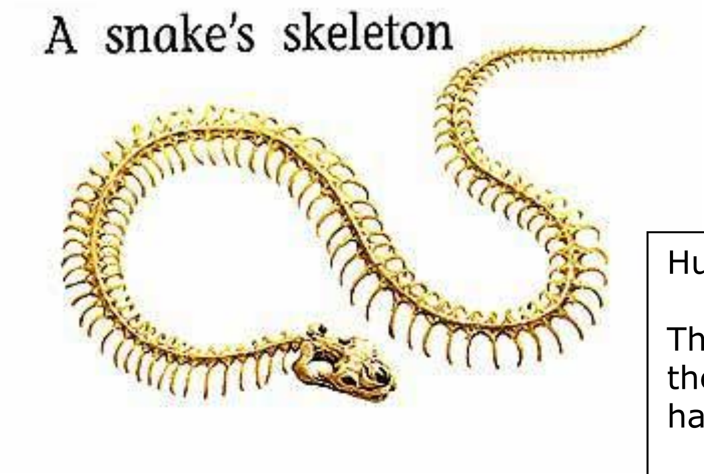
Snakes

Snakes are a very mobile animal; they have evolved a specialised system that allows this. The key to snakes' agility is hundreds of vertebrae and ribs. Ventral scales, these specialised rectangular scales line the underside of a snake, corresponding directly with the number of ribs. The bottom edges of the ventral scales function like the tread on a tire, gripping the surface and propelling the snake forward.
Due to the structure of the snakes' vertebra it is extremely flexible, allowing the snake to negotiate the smallest of spaces.



Worm anatomy





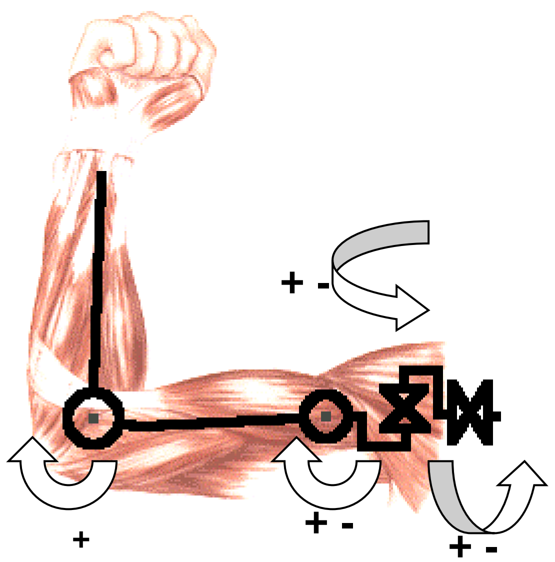
Human/mammal arm

The human arm is also very mobile; unlike the snake it is a series of different joints that have particular ranges of movement.

The shoulder is comprised of a ball and socket joint. A very mobile joint also found in the hip. It has two rotational axis and a hinge joint in both – and + directions.

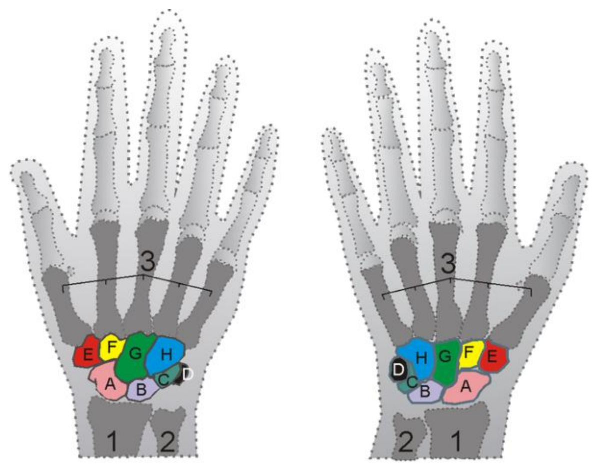
The elbow is a single hinge that only has a + displacement.

The wrist is a very special type of "joint", it's not a normal joint in that it is only two concave plates held together by tendons that just simply move over each other. This allows a great degree of flexibility in the wrist.



Worms have a very specialised method of movement. Because they have no solid structure they can't anchor muscles to a bone and use it to create movements. Instead they have two sets of muscles. Circular muscles are along the length of the body. Longitudinal muscles run down the length of the body horizontally. They work together by sending a wave of contractions along the body that slowly pulls the worm foreword.

Wrist bone structure

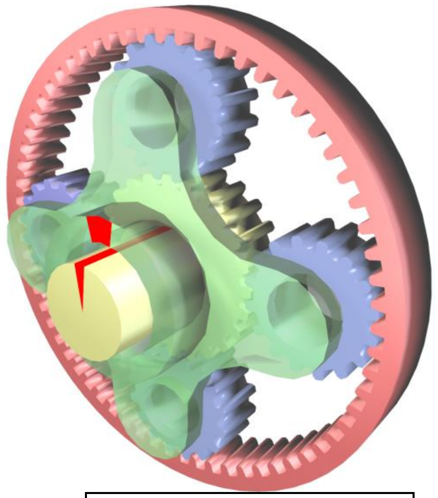


Conclusion

Animals have evolved over millions of years to end up at their current motion solutions. Each method is tailored specifically to the species and its environment. Trying to mimic these natural movements can be very advantageous. In trying to mimic a snake, a robot cold possibly be designed to have excellent flexibility or trying to copy a ball and socket joint a robot will have an extremely agile joint.

Research Motion

This project will have a lot of moving parts, and it is well known that the more moving parts you have the more chance of things going wrong. That is why it is imperative that all moving parts are designed and integrated as well as possible to the highest quality standards.



Planetary gears

A brushed motor is a very useful device. It comes in many sizes and its simple design makes it very reliable. It is likely that there is a motor for each conceivable use, so I could find a motor that suits my needs.

Many of the brushed motors need to be geared if they are to be of any use, a gearbox can make a motor very powerful. Also with planetary gearboxes, this allows the previously large gearboxes to be made very small.

However due to the fact that it relies on mechanical contacts to commutate the motor this causes sparking. This leads to a lack of efficiency, heating and worse of all electrical noise. The electrical noise can be suppressed using filter and capacitor arrays.

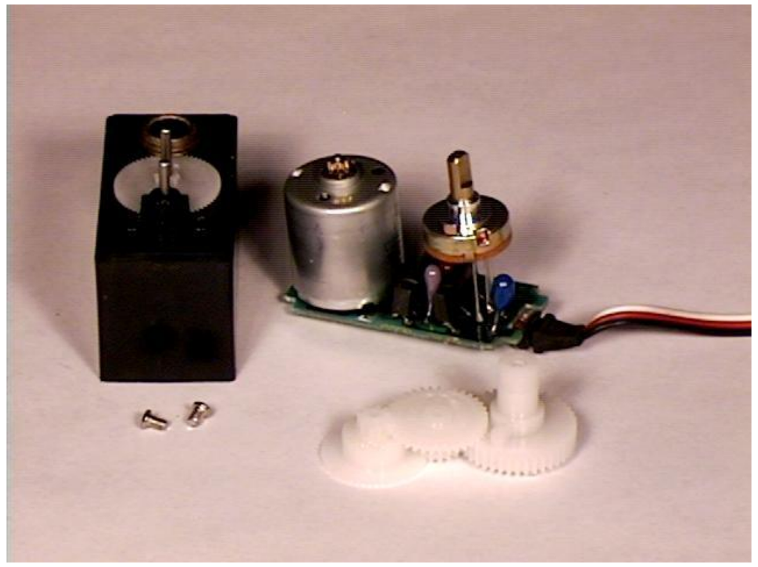
In a brushless motor, the electromagnets do not move; instead, the permanent magnets rotate and the armature remains still. This removes the problem of how to transfer current to a moving armature. In order to do this, the commutator assembly is replaced by an electronic controller. The controller performs the same power distribution found in a brushed DC motor, but using a solid-state circuit rather than a commutator system.

Brushless motors offer several advantages over brushed DC motors, including higher efficiency (upto 90%) and reliability, reduced noise, longer lifetime, elimination of sparks from the commutateor , and less electrical noise. The maximum power that can be applied to a brushless motor is very high, limited almost exclusively by heat, which can damage the magnets. Brushless motors main disadvantage is higher cost, which arises from two issues. First the motors require complex electronic speed controllers to run. Second, many practical uses have not been well developed in the commercial sector. For example, in the RC hobby world, even commercial brushless motors are often hand-wound while brushed motors use armature coils which can be inexpensively machine-wound.

Servos are extremely useful in robotics. The motors are small, and are extremely powerful for their size. A standard servo such as the Futaba S-148 has 4.1 Kg/cm of torque, which is very strong for its size. It also draws power proportional to the mechanical load. A lightly loaded servo, therefore, doesn't consume much energy. The guts of a servo motor are shown in the picture below. You can see the control circuitry, the motor, a set of gears, and the case. You can also see the 3 wires that connect to the servo. One is for power (+5volts), ground, and the white wire is the control wire.

The servo motor has a control circuit and a potentiometer that is connected to the output shaft. This pot allows the control circuitry to monitor the current angle of the servo motor. If the shaft is at the correct angle, then the motor shuts off. If the circuit finds that the angle is not correct, it will turn the motor the correct direction until the angle is correct. The output shaft of the servo is capable of traveling somewhere around 180 degrees. A normal servo is mechanically not capable of turning any farther due to a mechanical stop built on to the main output gear. The amount of power applied to the motor is proportional to the distance it needs to travel. So, if the shaft needs to turn a large distance, the motor will run at full speed. If it needs to turn only a small amount, the motor will run at a slower speed. This is called proportional control.

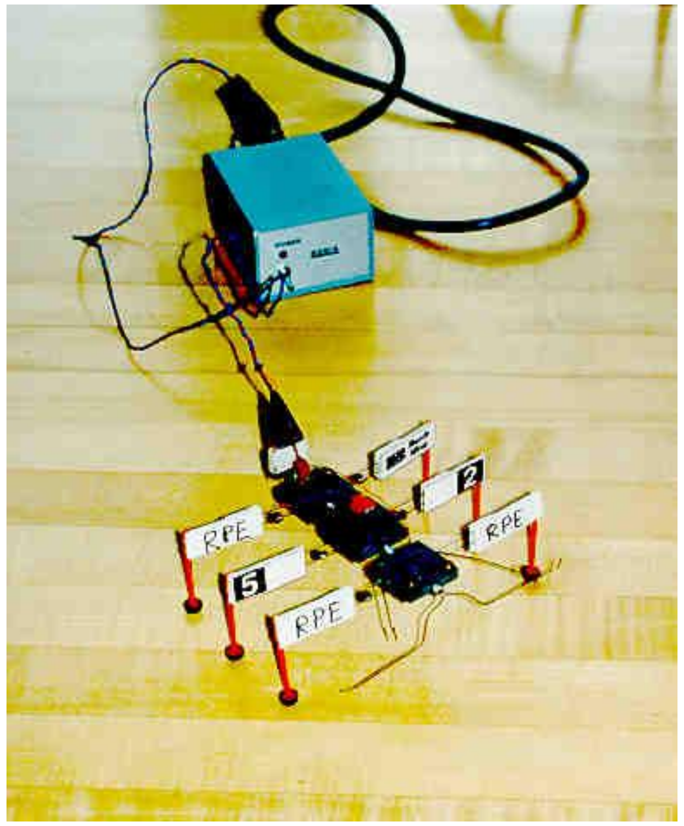
The control wire is used to communicate the angle. The angle is determined by the duration of a pulse that is applied to the control wire. This is called Pulse Coded Modulation. The servo needs a pulse every 20 milliseconds. The length of the pulse will determine how far the motor turns. A 1.5 millisecond pulse, for example, will make the motor turn to the 90 degree position (the neutral position). If the pulse is shorter than 1.5 ms, then the motor will turn the shaft to closer to 0 degrees. If the pulse is longer than 1.5ms, the shaft turns closer to 180 degrees.



Research Motion

Pneumatics is the use of pressurised air to effect mechanical motion. Pneumatics is employed in a variety of settings. In dentistry pneumatic drills are lighter, faster, and simpler than an electric drill of the same power rating (because the prime mover, the compressor, is separate from the drill and pumped air is capable of rotating the drill bit at extremely high rpm). Pneumatic transfer systems are employed in many industries to move powders and devices. Pneumatic tubes can carry objects over distances. Pneumatic devices are also used where electric motors cannot be used for safety reasons, such as deep in a mine where explosive dust or gases may be present. A pneumatic system is very robust compared to hydraulics, and much less susceptible to leaks causing a problem. Because the fluid used is air there is no need for a return system.

However the system needs to be constantly pressurised, this will require a lot of power to maintain the compressor too much of a drain for batteries. So the Engine power could be used here. Also with pneumatic systems they are usually in large scale use, one big compressor serves a whole factory floor perhaps. It could be un practical to have a compressor on such a comparatively small unit. There would be a need for multiple tubes and control valves to control the system.



A small robot using muscle wires to control the movement of its legs

Smart wire or memory wire is a nickel/titanium alloy which when heated or a current is applied it contracts. This motion can be used to actuate small loads such as a lifting a lever. One advantage is its fast switch time as soon as the current is switched.

However a force is needed to return it to its un triggered position, such as a spring.

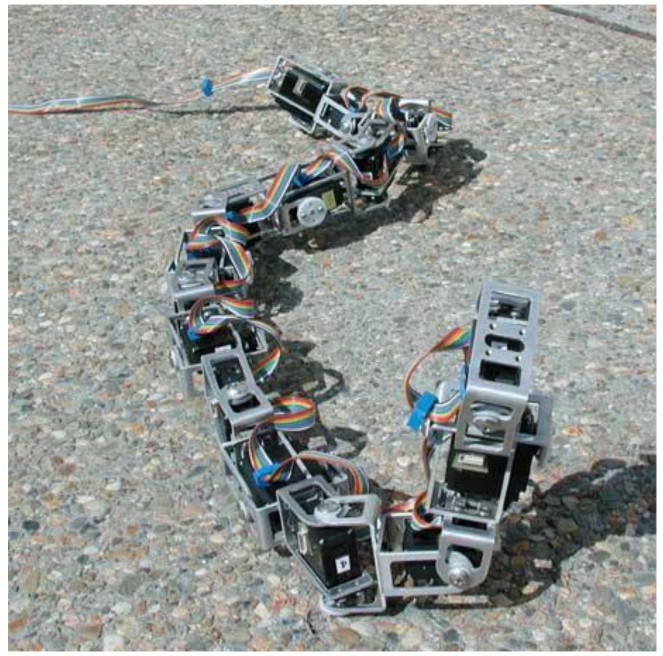
Conclusions

From this research it is apparent that there are many different ways to achieve motion in my project. Each method is suited to a different application, and it's early to know which methods I will be using until I am further into the prototyping. However I can already see that servos hold a massive potential due to their small size and incredible power. The difference between brushed and brushless motors become less apparent when they are running at high load, so there will need to be a selection between the two later on.

Robotic Arm Designs

Standard arm designs

As mentioned the standard arm design is made up of rigid segments with joints on the ends. This design has served very well as previously robots were built for purpose, and so the design was created accordingly. However now robotics is no longer confined to the shop floor of a car factory, their potential being realised groups are looking to create new robots which are flexible and versatile.



An exciting new type of robotic "animal" is currently being researched and developed by many organisations around the world. This new design is under the banner of a "Snake Bot", i.e. a robotic snake. This design totally breaks free from the standard designs of robotics. Like a snake the robot has segments which are individually controlled, therefore a very flexible design emerges. This particular design is a NASA design; the segments are actually made up of the servos which move them! This makes it very light.

This is an example of a revolute co-ordinate arm available from Rapid as an education pack. The separate segments can be seen and are actuated by motors. The motors have been connected to a bevel gear train, to increase torque and preserve the orientation. The gear mechanism to close the front gripper arms can be seen clearly. This is a very complex arm, and to try and use motors (brushed or brushless) in such a gear arrangement would be very difficult.

This is another example of a revolute co-ordinate. However this design uses servos on either end of rigid segments. Servos are a very good way to actuate joints, as they already have the internal gear train necessary for high torque. Also the ability to know their position will make controlling the arm very easy. This particular arm has been mounted on a buggy for extra mobility.

Conclusions

From this page detailing two types of robot design I can choose the type of arm design I wish to develop.

I feel that the snakebot will give a genuine exciting and challenging project. This is a relatively new branch of robotics and would give me an opportunity to truly innovate.

Also I can also now choose the servo as my method for actuation in my robotic arm. They have come out ahead of all other alternatives I have considered. They are cheap, reliable, small, powerful and simple to use.

Client Interview

Robotics has been established as a science for many years. There are many types of robot arm in use by industry or any other use.

However the type of arm I am seeking to create is very different, and there are only a few organisations working on the same concept. These include NASA, seeking new ways of planetary exploration, OC robotics that only specialise in snakebots and the robotics institute in the USA.

So called "snakebots" add a whole new dimension to robotics, as science attempts to imitate nature. "reaching the unreachable" is the motto of OC robotics.

Another company that has a robotics connection is "QinetiQ". It does not have any Snakebot developments however they have recently launched the talon robot, a mobile bomb disposal robot. This robot has been ordered by many armies including a very lucrative contract with the US army. What the talon robot does better than its competitors is that it delivers maximum performance for minimum price.

For those reasons I was eager to speak to an engineer from QinetiQ in a "client" situation, to talk about my robot in the talon context.

An early NASA Snakebot

A talon robot in the field with the US army

Client Interview

(Name Removed)responding to a few questions I posed to him regarding QinetiQ and the talon robot.

Thank you very much for your reply. My interest is specifically in the robotic arm of the talon unit. The talon arm is like many arm designs in that it uses rigid sections with actuated joints. My arm is much like a snake, the arm is split into segments and those segments can move independently. Please find attached a picture of 2 segments of the arm. This allows a great range of movement, more so than typical designs. This would be very useful for example in ordnance disposal where an operator will benefit from the maneuverability to move a camera carefully and precisely around the area.

That is certainly one useful ability in ordnance disposal. Precision is not always required, but for e.g. looking inside cars from the outside, a snake arm is one solution.

These guys make them: http://www.ocrobotics.com/ and have some impressive videos of their arm's ability to move inside a complicated structure by being able to move the tip, and have the rest of the arm 'follow' (like something out of 'The Abyss' presumably) it into the structure. That's not an easy control algorithm to write though.

My project portfolio requires me to ask the opinion of a "client", and I hope that you, as a professional engineer could possibly be my client and answer these questions if you are able to. I myself am hoping to become an engineer and I would appreciate any input.

1. To what extent do you think that the "typical" robot arm designs are limited?

A typical arm is normally made of a bunch of rotational and prismatic (telescoping) joints, in order to be able to move around a workspace, and then be able to acheive any orientation within that workspace. The talon robot only has three degrees of freedom, its lower and upper arms move, and its wrist rotates.

The British Army currently uses a robot called Wheelbarrow, which has a bunch more degrees of freedom, and the forthcoming new robot has 9. This allows it to reach inside a vehicle and have a rummage around.

Control of a robot arm gets more difficult as you add more degrees of freedom, as the number of possible solutions to configure an arm go up, which means you need more CPU power to drive the thing. You also need to present the control to an operator in an easy-to-use manner. Also, the arm needs to be able to lift things, and each joint must be able to support the weight of the arm and the object being lifted, with one joint strong enough to move the arm as well.

You also have to get all your cables and power up through the arm.

2. Do you think that my design will be able to overcome most/some of the shortcomings in "typical" designs? If so how?

A snake arm (as OCRobotics point out) has the advantage of being able to get into more complicated spaces and also because it has so many 'joints' individual sections aren't required to actually rotate over 360 degrees etc and so the problem of transmitting power and data through sliprings does go away.

Presumably if all your joints are identical, this gives you a modular design and you can choose an arm length to suit each mission, and have a reduced number of spare parts to maintain.

3. Do you think that my arm design would be useful in the same context as the talon robot? If so in what situations?

Hmm. The Talon is popular because it is comparatively cheap, and comparatively robust. Snake arms in general aren't cheap, and I'm betting they aren't fans of being blown up. If you're able to sell it as "Just throw away the top few links and slap on some new ones" you can probably go somewhere with it. However Talon doesn't sell itself really on degrees of freedom to my knowledge. I can't ask the sales guy to confirm as he's off for a month which is why you're getting me responding!

Inspection is obviously where your arm shines. If you put it on the end of the talon arm (the gripper itself comes off) then the talon could hold it up to a car, and your snake arm could look in and around, if it had a camera on it.

4. Do you think that my arm design has any shortcomings or do you have any suggestions for additions to improve my design?

Shortcomings of snake arms in general are their strength, and their complexity. You've seen the strength of the talon arm in the datasheets you've found. The new army robot is able to lift 20-50kg throughout its workspace, which is a 2-4m in all directions. I can't remember the torque a servo motor can sustain off the top of my head, but I don't remember it being brilliant. If you had a gripper on the end of it though, you could attach a lasso to things, and then let the stronger talon pull whatever it is you're after.

Complexity-wise you have more of a problem. A snake arm isn't different to a "typical arm", it just has many many more joints. This makes the control problem a nightmare, if each joint has two degrees of freedom, they multiply up quick. That's also a lot of power required to move it.

Improvement-wise, I'd be guessing here, as my mechanical background isn't so hot, but I'd say you want to get some more powerful motors, fit them with reducing, non-backdriveable gearboxes, and then you don't have to power the motor to stay in one position. At university, one group I know got free Maxxon motors by asking the company nicely! Possibly a bit overboard for your project, I don't know.

If you were trying to market this, I'd recommend going for cheap and replaceable. That's what the US Army is after. Some RCVs they use in Iraq are just remote-controlled cars that they drive into bombs. It solves the problem for them.

5. In your opinion do you think that the innovations and developments I have so far achieved in my project would fit in and work (appreciated) alongside current technological developments by quinetiq engineering teams?

Well, QinetiQ doesn't look at snake arms, as we wouldn't try to compete with OCRobotics in that area, to my knowledge. In terms of getting an idea of what robots are used for, other companies who make Talon-ish things are iRobot, who make Packbot; Remotec UK make the wheelbarrow, and are making the next gen army robot; and AB Precision make some kind of inspection robot I think.

Obviously they're our competitors so they're all wrong!

Once again thanks for your reply and the address of fostermiller, which was very useful. If you would like any more technical information on my arm, then please email me.

Good luck with your project. If there are any other questions, please ask. I'd be interested to see how it goes.

(name Removed)
Dismounted & Force Protection

Research Conclusions

Stephen Bridges at QinetiQ he has made some very good suggestions and pointed some useful end uses for my project. Because I have now benefited from the input of an engineer I can focus my arm for catering to the inspection needs of bomb disposal for example. This is a well suited application because the arm will still need to demonstrate how it is different from standard arm designs.

So in response to my interview I am able to produce a concise final specification which adds more detail on my initial spec and will serve as a vital reference point to make sure my design is on track.

Final Specification

- The robot arm will be a “Snake” design.
- The arm must be safe to use and be around.
- The arm needs to be relatively simple to use.
- The electronic control units must be robust and reliable.
- The arm will have a camera on the end for feedback.
- The arm must be highly versatile.
- The arm will be capable of being wirelessly controlled.
- The arm must be tough.
- The arm must be light.
- The arm needs to be small.
- The arm will be easy and simple to add and subtract modules from.
- The arm must be comparatively dirt cheap to buy and have low maintenance.
- The arm must be quick to set up.
- The arm must be able to use batteries for power.

At the end of this research section I have gained a lot of useful information. I am able to now say that I will be using:

- Servo motors for motion of my arm as they are cheap very powerful and easy to use.

  Motors would need me to create complex gear trains to transfer their rotation efficiently into robotic motion. Muscle wire was an interesting technology to learn about, I feel at the moment it is nowhere near advanced enough to meet my needs. The pneumatics I think would work on a large scale as the amount of valves and tubing required would be very large.

- XBee wireless control. This offers the most cost effective radio solution. It is so simple to use and it operates on an extremely robust 2.4GHz frequency within its own secure protocol. This would make it ideal for 100% reliability in tough situations.

- PICAXE microprocessor. I have a lot of experience with the PICAXE platform and it is also cheap. As this is not a software based project the PICAXE will provide plenty of computing power to control the arm.

Although this is the research conclusions I can not make final decisions on everything I want to use. The components detailed above make up the main body of the project, and it was important to be clear and decide on these items first. The other details such as the material to be used and power source will be decided in the early prototyping stages as I will begin to see how everything fits together as the project takes shape.

A look at industry

In industry large companies there is a whole department dedicated to R&D (Research and development). The R&D team can spend years researching and exploring the development of a new product. Sometimes these have massive funding such as the new USAF air superiority fighter, F22 raptor a project that began in the 1970’s with a budget into the billions, which has only recently been completed last year.

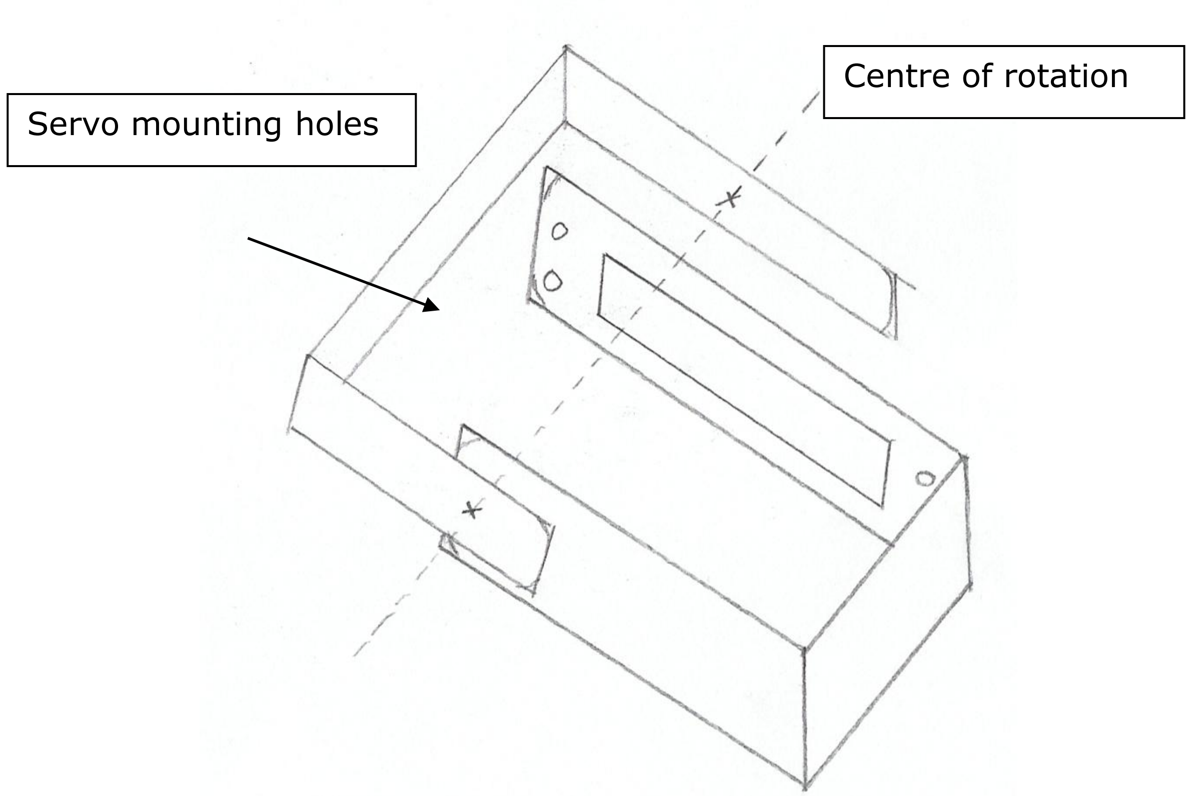
Prototyping: servos

Using servos could be a very good solution to the construction of my snake arm. They are relatively cheap and have a very high power to weight ratio. They are a self contained unit so there is no need to worry about gears and alignments, all there you have to do is connect to tits output shaft.

The difficult part was to design an effective and efficient way to attach the servos together and maintain maximum mobility but minimum weight.

This is the design I came up with. It is a two part unit. One part will have the servo mounted on it, and a second connecting arm will link with the servo and will transfer the force. This single unit can then be repeated along the length of a snake arm.

This is a very good design as it minimises material and is very rigid due to the bends in the material.



This is my first physical prototype of the units. As can be seen the unit fits very well together and is very compact. The material being used at this stage is 1.2mm aluminium, as there is a large supply at school.

Materials

A careful choice of materials must be made to ensure a lightweight design and easy construction.

Metal would be the obvious choice as it can be cut to size and easily bent. There are only two viable metals to consider here.

Stainless steel is a very strong metal; it is corrosion resistant and very tough.

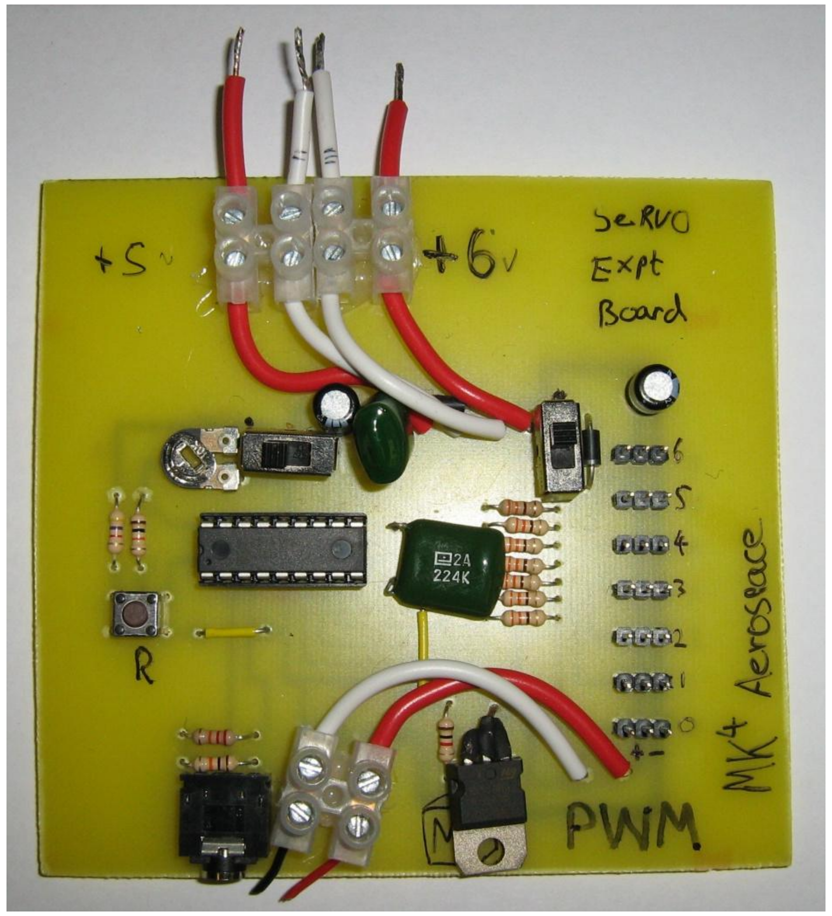
Aluminium has an extremely high strength to weight ratio, making it an excellent choice in aerospace technology. It is softer than steel and can be bent easier. Aluminium is also corrosion resistant.

Plastic is also an option that needs to be considered.

Acrylic can be cut to shape easily, however it needs heat to be bent. It is chemical resistant and lightweight.

Injection moulding could produce multiple copies of my units very easily and quickly. However it would only be an option for industry as the set up costs are into the £1000.

Prototyping: servos



To understand how to control the servos I made a servo experimentation PCB. This board allows 7 servos to be controlled by a PICAXE 18X microcontroller. (left)

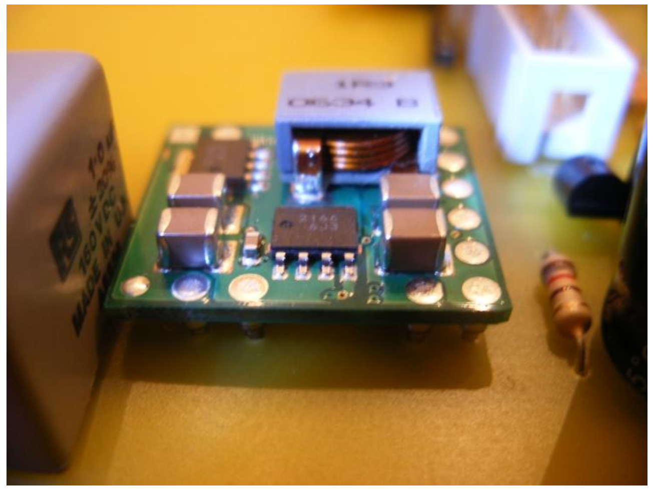
This is some information from the PICAXE data sheets on servos.

Servos are a very accurate motor/gearbox assembly that can be repeatedly moved to the same position due to their internal position sensor. Generally servos require a pulse of 0.75 to 2.25ms every 20ms, and this pulse must be constantly repeated every 20ms. Once the pulse is lost the servo will lose its position. The servo command starts a pin pulsing high for length of time pulse (x0.01 ms) every 20ms. This command is **different** to most other BASIC commands in that the pulsing mode **continues** until another servo, high or low command is executed. High and low commands stop the pulsing immediately. Servo commands adjust the pulse length to the new pulse value, hence moving the servo.
The 'servo' command initialises the pin for servo operation and starts the timer.

Servo cannot be used at the same time as timer or pwmout/hpwm as they share a common internal timer resource. The servo pulses are also temporarily disabled during timing sensitive serin, serout, sertxd and debug commands.

Example of servo Program

```
init: servo 4,75           ` initialise servo
main: servopos 4,75        ` move servo to one end
pause 2000                 ` wait 2 seconds
servopos 4,225             ` move servo to other end
pause 2000                 ` wait 2 seconds
goto main                  ` loop back to start
```



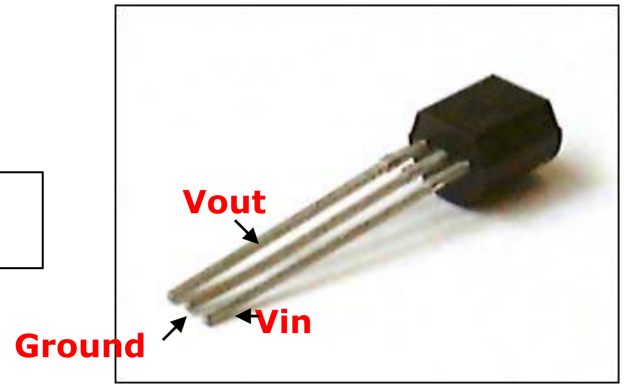
Servos need a relative high current; some can draw up to 1A when under large strain. As my design may require many servos working together I will need a high current. The conventional way to achieve a large current is to use a large capacity battery such as a lead acid, however that would be very big and heavy and that would only possible be able of delivering a sustained 2-3A.

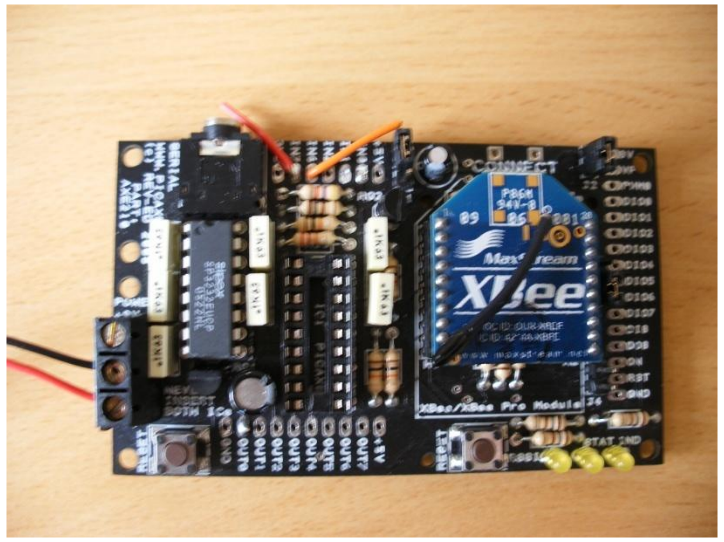
I have found a very good solution to this power problem. The solution is an on board transformer which is capable of delivering a massive 16A! This is even better because the output voltage can be varied to 5.5V, right in the optimum servo voltage. (left)

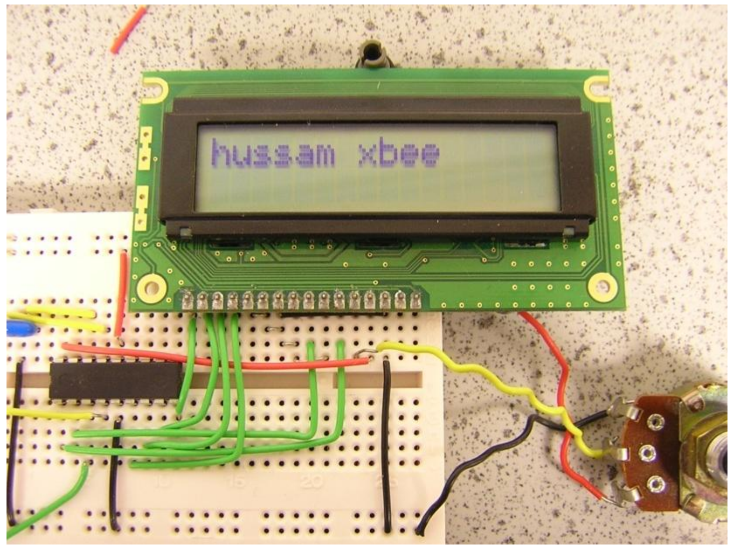
This module is known as a DC-DC converter, and huge leaps in sub-miniature electronics have made it possible to create this. It was made by Texas instruments a global semiconductor company; they also operate a product sample policy which allowed me to get two of these modules to use in my project.

XBee Development

The XBee requires 3.3v to run; my PICAXE and majority of the circuit will use 5v. So to achieve the 3.3v I will be using a voltage regulator.







The XBee development board (top left) is an excellent way to learn and understand how to use the XBee module.

I wish to use the module to transmit information between two PICAXE's using the serial in/out commands so that it is effectively as if they are connected by a wire. So the first thing to do is to make sure that the PICAXE's can exchange information through a solid state connection before introducing the Xbee.

The PICAXE serial commands (in this case serout) have syntax a follows:

Serout pin, baud rate, (Data…)

The important part here is the baud rate. Baud rate is the speed at which telecommunicated data is transmitted, measured in bytes-per-second (BPS). Typical PICAXE baud rate is 2400, for the receiving PICAXE to correctly input the incoming data the serin command must also have the same baud rate, i.e. (baud rate is relevant whenever electronic devices are exchanging information

Serin pin, baud rate, {#} variable,{#}variable…

Once the information is received it is inputted into the variables b0-b13 for use later. Also another feature of the serial commands are the use of qualifiers, qualifiers are used to make sure the correct data is inputted by the PICAXE so that any stray signals are not an issue. E.g.

Serout 7, T2400, ("ABC"," 1")
Serin 7, T2400, ("ABC"), b1

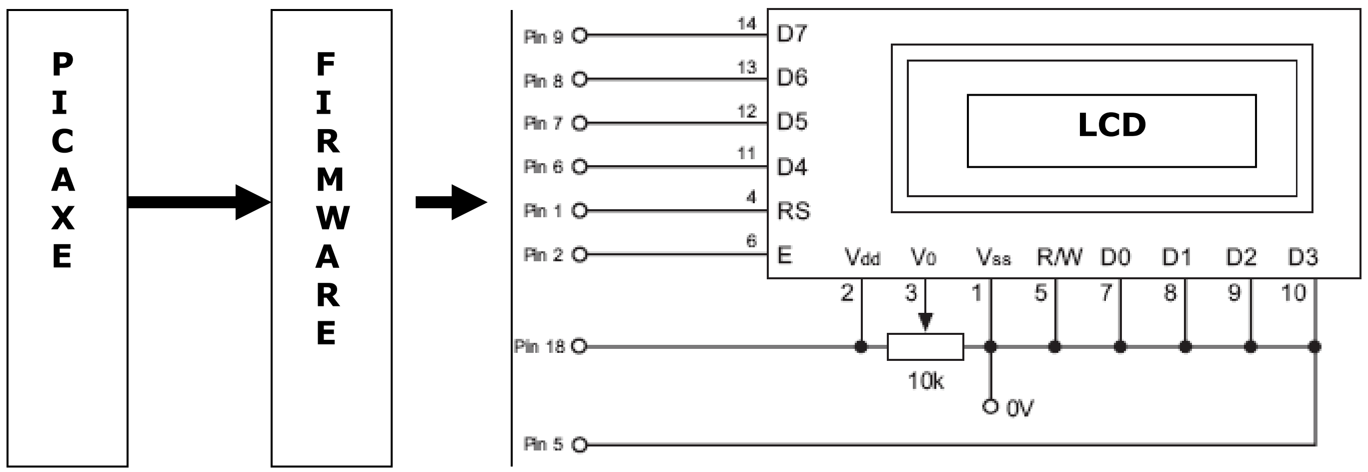
A serial signal is transmitted from pin7 at a baud rate of 2400 with the qualifier "ABC" and it's sending 1 as data. Then the serial is being received at pin7 at the same baud rate and once it receives the qualifier "ABC" it inputs value 1 into the variable b1.

So when I introduced the XBee I just replaced the wire connection with the data in and data out connections of 2 XBee modules, and I was going to transmit information to be displayed on an LCD screen. However there was no success at first, there was random characters appearing on the screen. After investigating the problem I found out that the baud rate of the XBee itself has to be configured, its default is 9600, so all I had to do is reprogram the XBee via the development board and supplies Max3232 IC to 2400, PICAXE baud rate. This solved the problem and my successful transmission can be seen bottom left.

Prototyping: LCD Screens

My robot will have a menu system to show various options to the user, such as switching on lights or changing programs. This menu will be displayed on a LCD screen.

This is a 20X4 line serial LCD screen. It can be operated using a serial firmware chip and a PICAXE. The PICAXE generates the serial signal which is sent to the firmware and then an output appears on the LCD screen. This would be able to display any text.



The command to send data to the firmware is the "serout" command
Syntax:
SEROUT pin,baudmode,({#}data,{#}data...)
The serout command is used to transmit serial data from an output pin of the microcontroller.

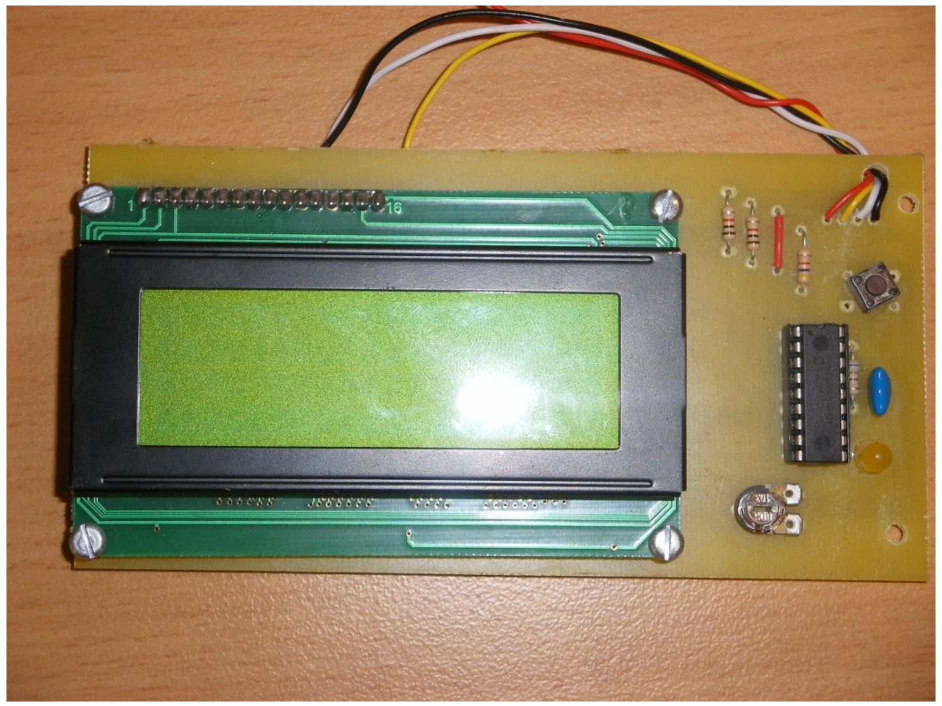
E.g. serout 7,T2400, (254,128, "HELLO")

Serout 7: select pin 7 to output the serial data
T2400: the baud rate is 2400baud
(254,: 254 is the prefix with all serial LCD screens
128,: This selects the first line as where to start showing characters
"HELLO": The characters I wish to display, in speech marks to show they are ASCII characters.

An alpha-numerical LCD screen is able to display characters A-Z numbers 0-9 and some special characters. There are many different types of LCD screens on the market, offering a similar product but require different methods to run.

Serial LCD's are one option; they are controlled by serial data source and a firmware chip. The serial interface makes them easy to use and they are widely available in different sizes.

LCD Screen



Prototyping: User Interface

My snake arm obviously needs to be controlled. This means that I need to develop a user interface that work well. I decided to simplify the movement of the sake by splitting it into two, the head and rest of the body. This eliminates having to individually control each servo.

The head is made up of the two end servos mounted at right angles, allowing pan and tilt motion. The rest of the body 3rd servo downwards, each servo would step left/right and when it reaches the end of its travel the next servo down would begin to move. Also the whole arm would be lifted from the root.

Also ergonomics and anthropometrics is very important when designing user interfaces. The design needs to be comfortable to use, and all the features must be reached by users of all sizes. On the right is a table of adult anthropometric hand data. This is the sort of parameters that all designers work around to allow their product design to work well.

My chosen solution to all the above factors is a game style pad. I intended to use one joystick to control the head and one for the rest of the body. I would need to tap into the circuitry for the analogue sticks and interface them with the PICAXE. This joystick was designed to be used for gaming, so it already very comfortable to use and fits all hand sizes. Coincidentally OC Robotics also uses a joystick game pad to control their robots…great minds…?

The game pad

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Table 5.1 Anthropometric estimates for the hand (all dimensions in mm).

Dimension	Men 5th %ile	Men 50th %ile	Men 95th %ile	Men SD	Women 5th %ile	Women 50th %ile	Women 95th %ile	Women SD
1. Hand length	173	189	205	10	159	174	189	9
2. Palm length	98	107	116	6	89	97	105	5
3. Thumb length	44	51	58	4	40	47	53	4
4. Index finger length	64	72	79	5	60	67	74	4
5. Middle finger length	76	83	90	5	69	77	84	5
6. Ring finger length	65	72	80	4	59	66	73	4
7. Little finger length	48	55	63	4	43	50	57	4
8. Thumb breadth (IPJ)[a]	20	23	26	2	17	19	21	2
9. Thumb thickness (IPJ)	19	22	24	2	15	18	20	2
10. Index finger breadth (PIPJ)[b]	19	21	23	1	16	18	20	1
11. Index finger thickness (PIPJ)	17	19	21	1	14	16	18	1
12. Hand breadth (metacarpal)	78	87	95	5	69	76	83	4
13. Hand breadth (across thumb)	97	105	114	5	84	92	99	5
14. Hand breadth (minimum)[c]	71	81	91	6	63	71	79	5
15. Hand thickness (metacarpal)	27	33	38	3	24	28	33	3
16. Hand thickness (including thumb)	44	51	58	4	40	45	50	3
17. Maximum grip diameter[d]	45	52	59	4	43	48	53	3
18. Maximum spread	178	206	234	17	165	190	215	15
19. Maximum functional spread[e]	122	142	162	12	109	127	145	11
20. Minimum square access[f]	56	66	76	6	50	58	67	5

Notes:
[a] IPJ is the interphalangeal joint, i.e. the articulations between the two segments of the thumb;

HANDS AND HANDLES 85

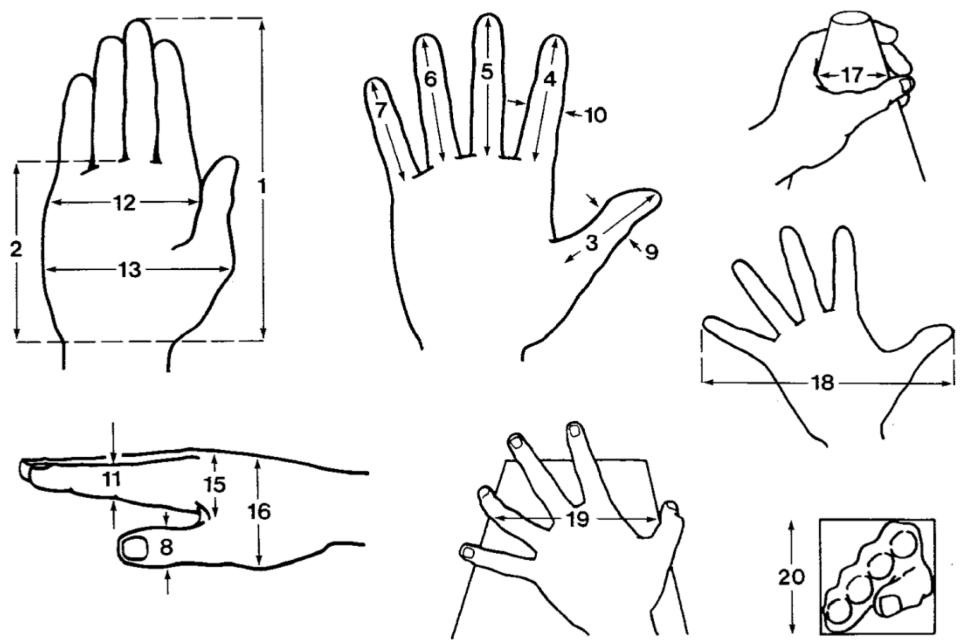


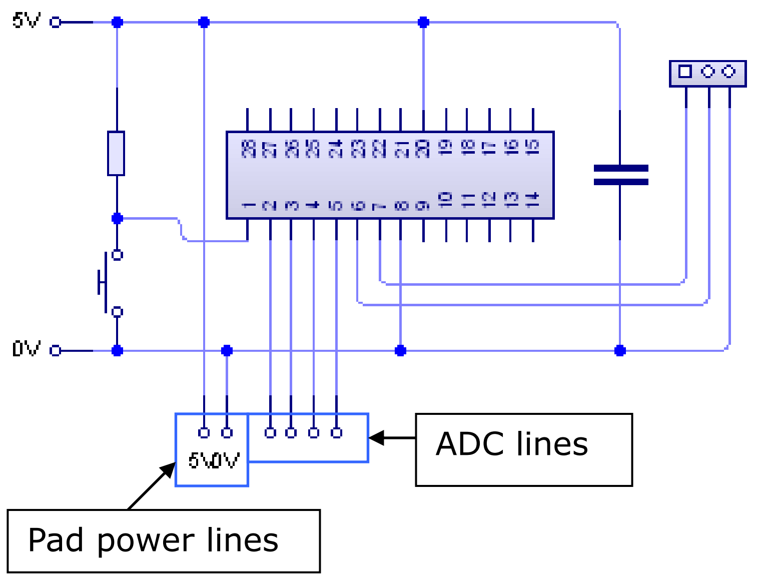
Figure 5.1 Anthropometry of the hand, as given in Table 5.1.

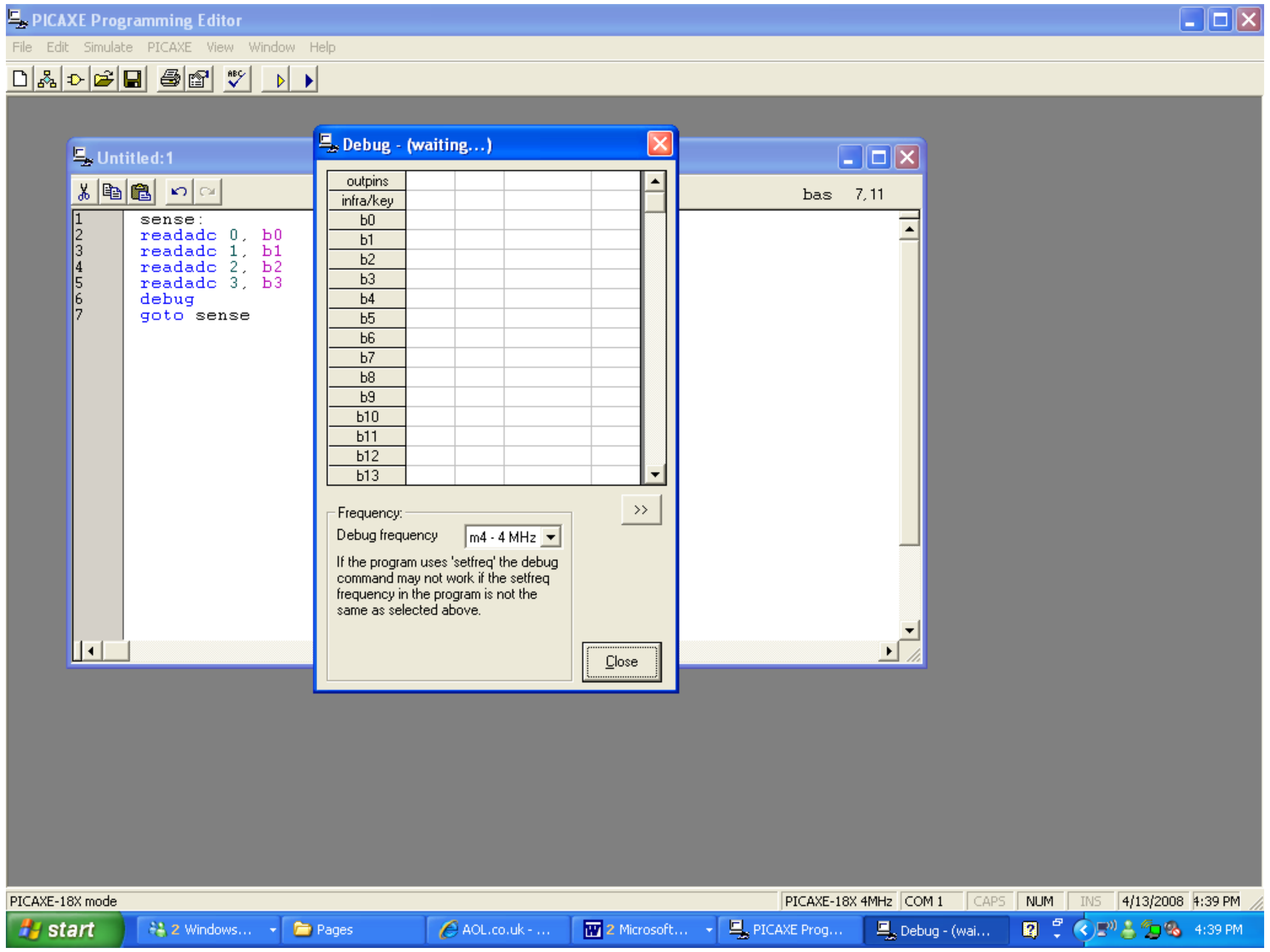
Anthropometric data from Bodyspace

Prototyping: User Interface

Interfacing with the joysticks was not too difficult; they work quite simply by moving a variable resistor, so the voltage outputted is linked to the position of the joystick.

The joysticks have 2 resistors each meaning that I would need 4 channels to input their values. The PICAXE 28X1 has 4 ADC lines that can be linked to these joysticks. I opened up the controller and saw that the analogue sticks were on their own board; this made it very easy to isolate them. I then just proceeded to attach the 8 wires from this board (2 power lines, 4 ADC lines, 2 switches) to the PICAXE via a ribbon cable. Below is the circuit diagram for this set up.





Above is a screenshot of the PICAXE programming editor. The program I was using is visible and that basically cycled through the 4 ADC channels and then stored their values in the variables before outputting the values of these variables via the debug command.

The debug command was very useful as it shows me what data is moving around in the PICAXEs internal RAM. Because this worked so well I can now easily, by using "if" and "goto" commands use the values stored in the variables to control the robot.

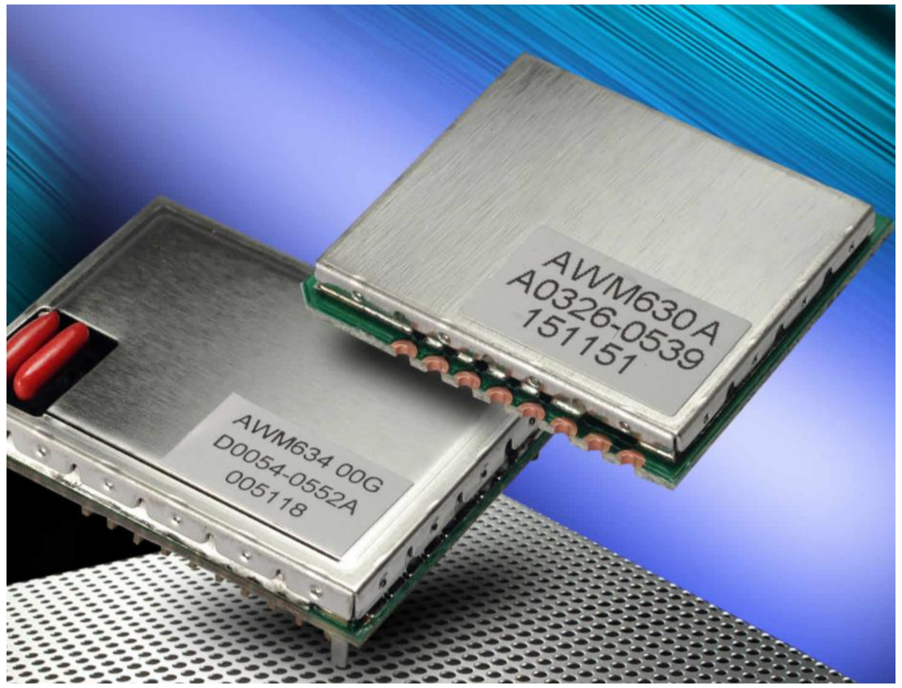
Prototyping: Audio and Visual

As I now intend to relay a video feedback from the robot to the controller, I would need a suitable camera. The camera needs to be small and light, and most of all very simple to interface.

I could immediately rule out camcorders, as they are not necessary for this. However the ability to be able to record the video would be an interesting future development of my project.

I eventually found a small CCTV camera, this was perfect. It is 2X2X2cm very light, it is full colour, has a microphone and interfaces via RCA cables which are a standard for AV products. I bought this module from eBay from China for a total of £13.

My overall design must not be too big, so it would be impractical to carry around a TV to view the camera images. I needed a monitor that was small and had an AV input to display the video. There are plenty of these around however they seem to be unreasonably expensive. It was odd to then find a portable Sony playstation one 5 inch LCD screen, with everything I needed for £25. This price was less than half of the monitors that were specifically made for portability. My screen came with its own power adapter, and I tested it by directly linking it to an AV source.



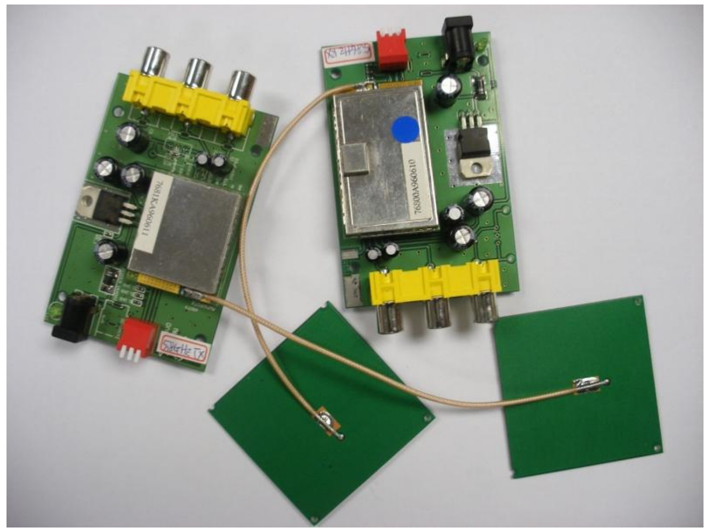
These are 2.4 GHz AV radio modules. They are very useful because they are a self contained circuit and all that is needed are the input and output sources for the video and audio. This module can handle stereo sound too. However when I first began to experiment with them I found that there was significant interference with the image on screen. The 2.4 GHz band is a very crowded one, Wi-fi systems operate on this frequency, as does Bluetooth, XBee modules and a number of other wireless appliances. This would have been fine if we the airwaves were digital, however as it is analogue it is very susceptible to interference. All the other named devices are digital and the XBee for example has an internal coding of its data so it will not be affected by interference.

Such a poor image quality could not be tolerated for my purposes. The camera image must be clear, so it can be used effectively as a feedback device. A solution had to be found. One idea was to shield the modules and all the signal lines. There was already substantial shielding on the modules, thanks to the metal case they are in. I needed to add more to this shielding. Despite using coax cable to carry all signals, capacitors on the power rail and leaving only the antenna exposed there was still considerable interference. It looked as if this problem could not be solved, and to prove it we put the modules in a metal box together and there was still interference. By this point there were other projects intending to transmit AV, so it was in all of our interests to find some sort of solution.

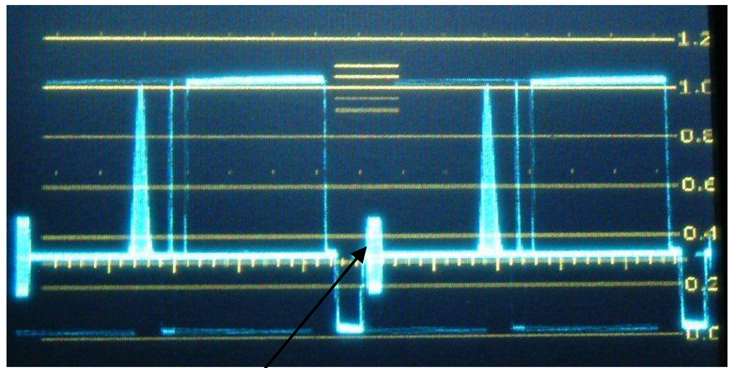
Prototyping: Audio and Visual continued

The cause of our AV transmission problem steamed from using 2.4GHz, as it was such a crowded band. We had found 5.8GHz modules also made by airwave. However there was only one supplier that we found, who was in the USA, and it would be expensive to buy. Sam Duke however a fellow technology student managed to contact Airwave direct and negotiated to buy a lot of 10 units of transmitter and receiver modules. The man we contacted was Johnny Chen, he gave us a very good price for this lot and included two free evaluation boards to help us experiment.

5.8GHz modules



A standard composite trace



The sync burst

We were very pleased to finally receive the 5.8GHz modules and to be rid of the interference problem. I hooked up two modules to the demo boards and successfully transmitted from a DVD player to the projector with no interference. However when it came to then testing it with my camera there was another problem. The image was moving up and down the screen and sometimes it would not display at all on the screen. My initial thoughts on yet more interference could not be true as two other classmates were transmitting fine.

Because the picture was moving up and down the screen, this lead me to believe that part of the composite signal was not being transmitted correctly. So I began using an oscilloscope to analyse the composite video trace, I was looking in particular for the sync signal. The sync is a short burst of signal that synchronises the input of the video with the display. Despite my investigations I could see no obvious difference between a full signal and my signal.

I also began to think why it would sometimes not transmit at all. Then I saw that when I darkened the environment it sent and when it became light it would cut out again, all the while still moving on the screen. On further investigation of composite video technology I found that a dark environment will give a lower voltage signal and a lighter environment will give a higher voltage. Then re examining the data sheet of the airwave modules, it needs an input voltage of no more than 2v peak to peak.

Again there was someone else with this same problem, and were working individually on a solution for the problem because theory were caused by different reasons. As it turned out it was the same issue. We ended up thinking the same solution, and when I came in to the lab to test my idea, I found my classmate with the same solution working. So that was one problem solved.

However my image was still moving around the screen. I began to think this was caused by my camera module outputting a different signal because my classmates who were using airwaves were sending from hard drive recorders, computers and other "standard" products.

I could still not find a solution from the oscilloscope traces, and on a thought I began to wonder about the capacitor that is in line with the video signal, and if that was somehow altering the signal. Proceeded to short across this capacitor and the signal stabilised and there was a crystal clear image on the screen.

I still do not know the exact reason for why this worked, but I think that the capacitor acted as a buffer to the signal or that it altered the signal.

Note: The AV side of the project was more complex than first anticipated; I encountered numerous problems and a large time between ordering the 5.8GHz modules and receiving. Inevitably this caused some lost time.

During the wait for the 5.8GHz modules to arrive I had to push ahead with the manufacture of my metal parts for the arm. Also because I was busy solving these problems I had to postpone completing my PCB designs as I was not sure if these 5.8GHz modules would work.

A look at industry

During the development of any product designers may encounter unexpected problems during their development stage, much in the same way I have. When products are late or delayed it is usually because there is an unexpected issue that has come to pass, these products could be delayed by up to a year in some cases. Unfortunately I do not have that sort of time.

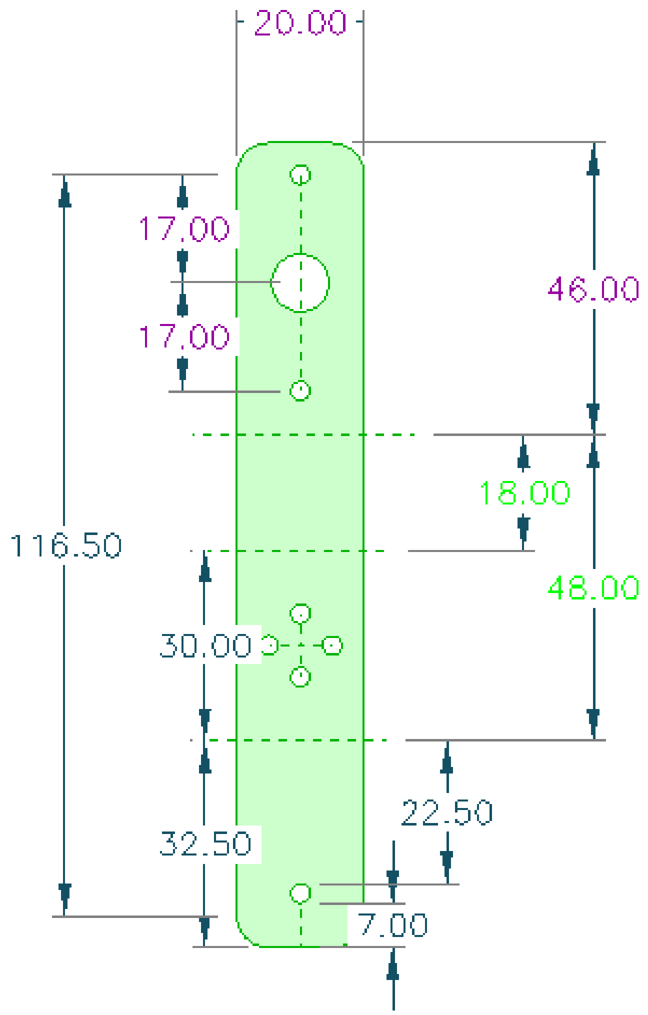
Pro/Desktop Drawings

Having decided on the design for the servo units I needed to begin the manufacturing process. The first stage was to produce accurate drawings with dimensions so I have an idea of the scale of the parts.

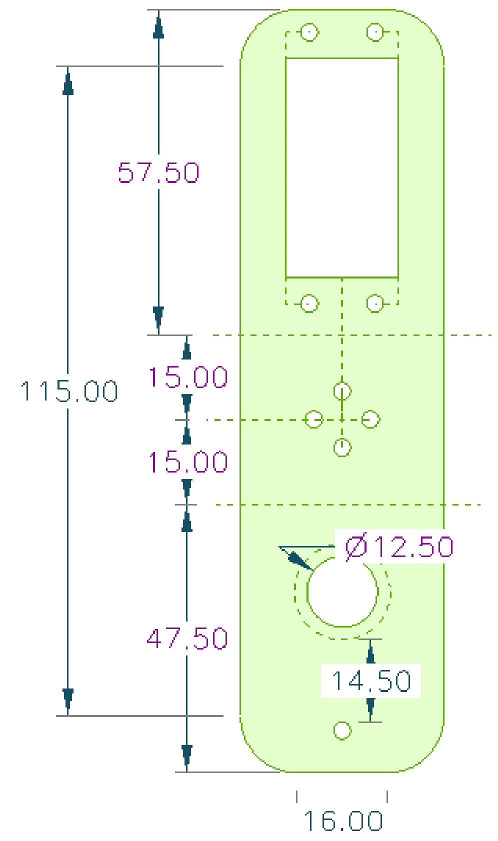
I used a powerful CAD package called Pro/Desktop. Pro/Desktop is a toned down version of Pro/Engineer an industry grade CAD package, however still very powerful. I drew the three parts as an engineering drawing, the accepted industry standard in presenting drawings.

A major advantage of using a CAD program is that it will ensure accuracy in my drawings. I can easily flip between different versions and update the designs accordingly. I can also compare the designs to each other to make sure everything is aligned.

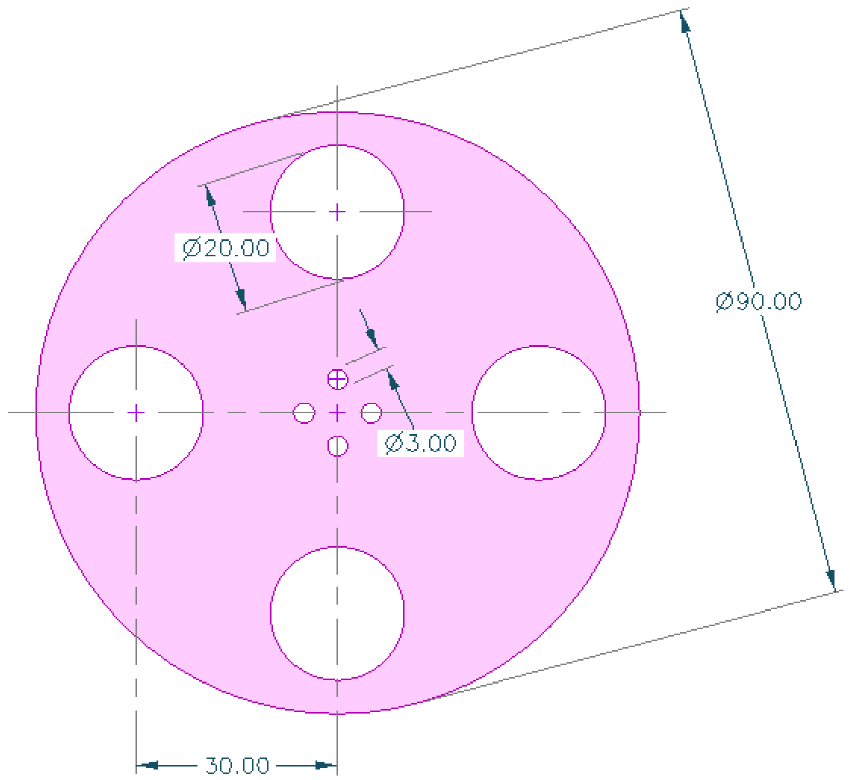
Servo Connect Plate



Main Servo Plate



Round Guard



Servo connect plate

- The arm that will transfer the force of the servo. It attaches via a servo horn fixed to the top, which in turn attaches to the servo output shaft.

Main servo plate

- Holds the servo in place with 4 mounting holes. It includes a large hole to allow the servo wire to exit without catching on any of the moving edges.

Round guard

- A new part which was designed to give the body extra width. Also four holes run along the length of the arm to allow the cables to pass along the length of the arm.

- All the units fix to each other by four bolts near the centre of each design.

Laser cut parts

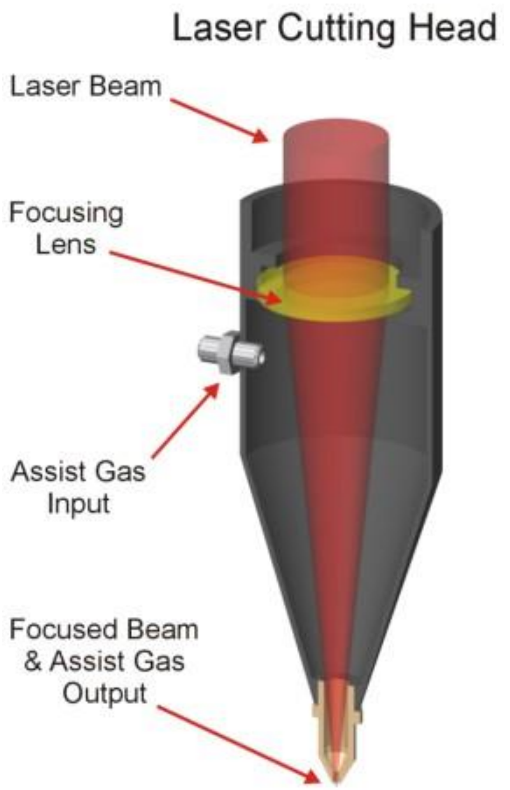
The manufacturing of identical parts is very difficult to do manually. For this reason I was seeking to have my parts made by a CNC machine. A CNC machine will be a very advanced piece of technology that is capable of manufacturing identical parts. There were many options to choose from such as rapid prototyping, milling machines and laser cutting.

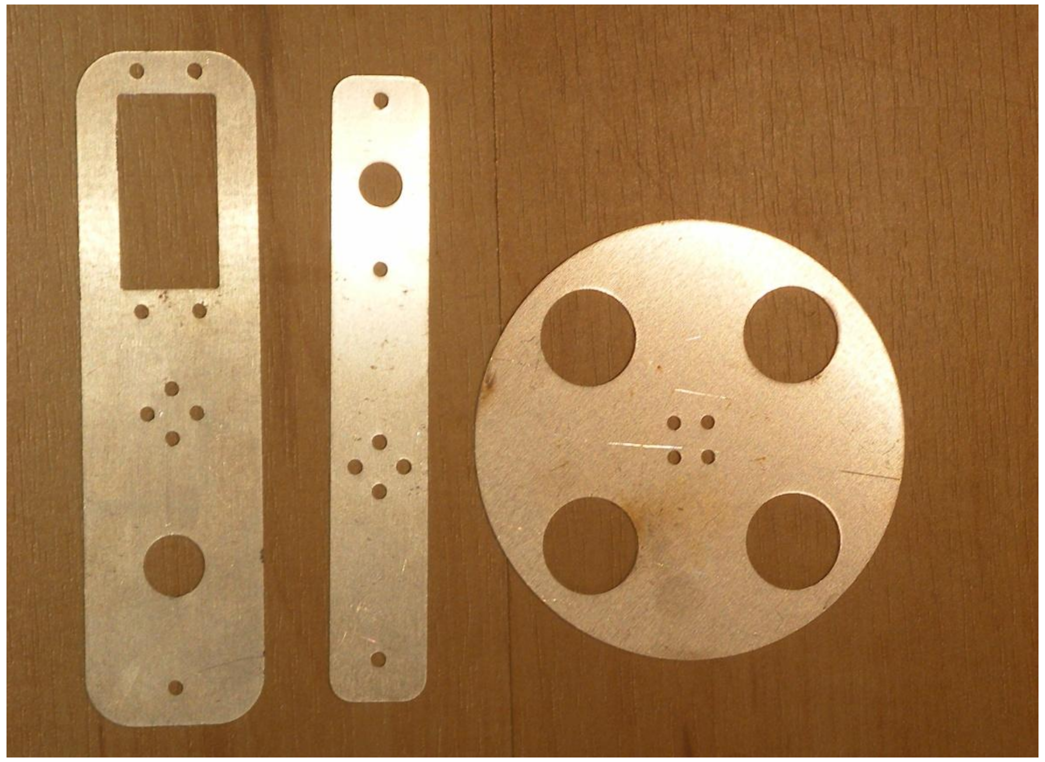
Whilst researching each of these possibilities the option of laser cutting became the most viable. I then decided to follow this option.

Laser cutting

Laser cutting is a technique where flat sheets of material are cut using a powerful laser. It has many advantages including low set up costs, very high accuracy and speed. Laser cutting will also allow me to use metal in the construction of the parts. I will be using 1.2mm aluminium as it's very light and strong and softer than steel, so easier to bend and cut.

Also because I used Pro/Desktop to produce my designs, the software can export the files with all the sizes into a format for the laser cutting machine.





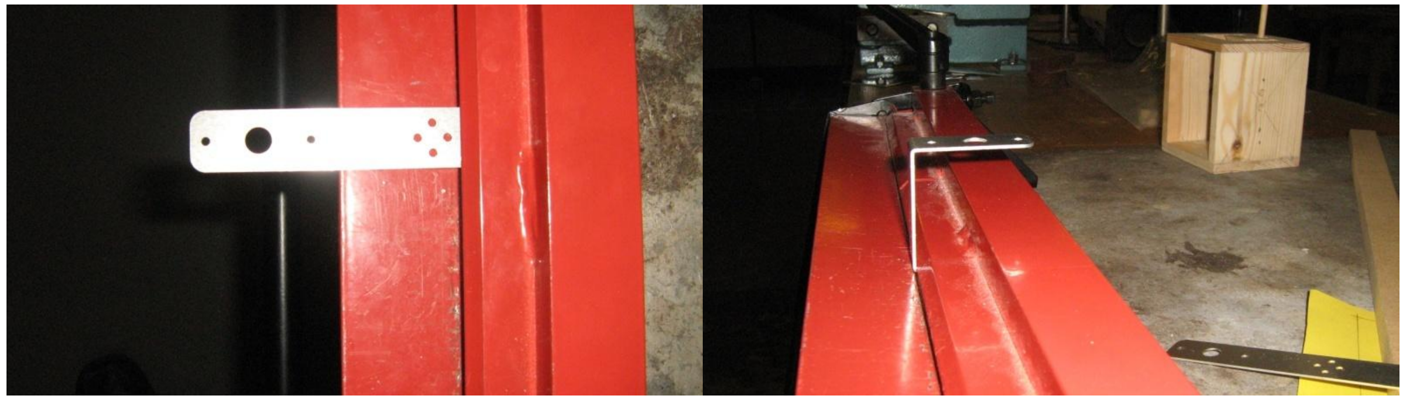
In laser cutting the heat of the beam is used to cut a material, in this case aluminium. Because the beam is so fine cutting to within 0.01mm is possible, and as the heat is focused on such a small area there is no chance of warping. Also there is no physical contact with the material, so the cuts are very clean.

Above you can see a shower of sparks as a metal sheet is being cut. The head of the cutter is very simple the laser is focused to a fine point and emerges surrounded by an assist gas. The assist gas is an inert gas, because the material becomes so hot the inert atmosphere stops any oxidation with the atmosphere. An example of an assist gas is nitrogen.

I contacted a local company called Laser Shape, laser cutting specialists. The whole process took less than a week; I emailed my drawings, received a quote, paid and collected my parts.

Above are my parts. As can be seen the quality is extremely good. I measured the parts and found them to be exact to my drawings. You can still see the scorch marks from the sparks during the cutting process, however they rub of. I am very pleased with the outcome and very glad to have chosen laser cutting.

Assembly 1



Having acquired all the components to build the snake arm, I will be making a small mock up of the final arm using two units.

I first had to bend the flat aluminium sections using a line bender. I was pleased to see that all the parts aligned perfectly too.

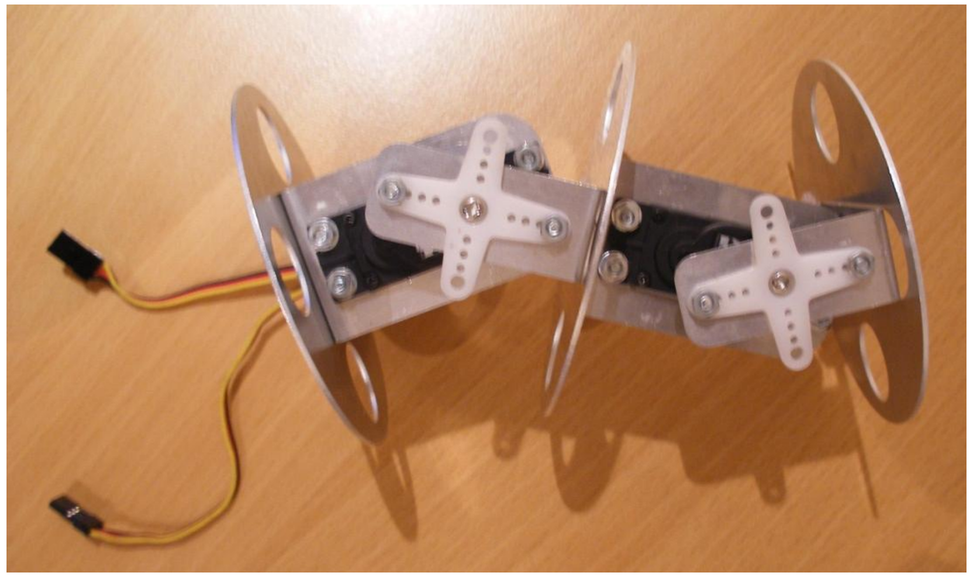
The servo I will be using is an Acoms AS-16. It has very impressive specs for it low price.

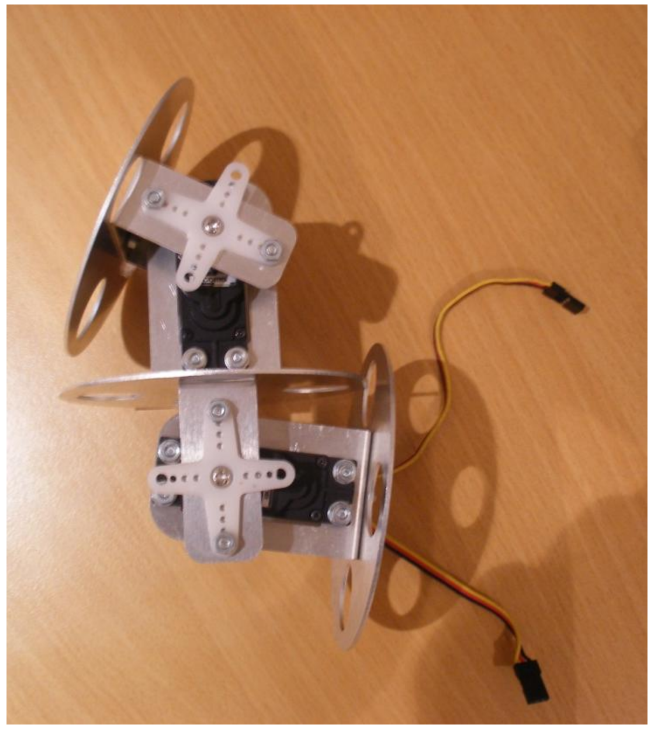
Specification
Dimensions (mm): 20.0 x 39.0 x 36.0
Weight (grams): 43.0
Speed (sec): 0.13/60deg
Torque (Kg.cm): 4.2
Nylon gears

The assembly was very simple because everything fitted together perfectly. Below is the mini snake arm composed of two units and two servos. It can be coiled almost 360 degrees. This shows the success of my design for the arm as it is very light and strong.

Quality control

To ensure that the pieces line up I must mark the metal carefully and accurately.



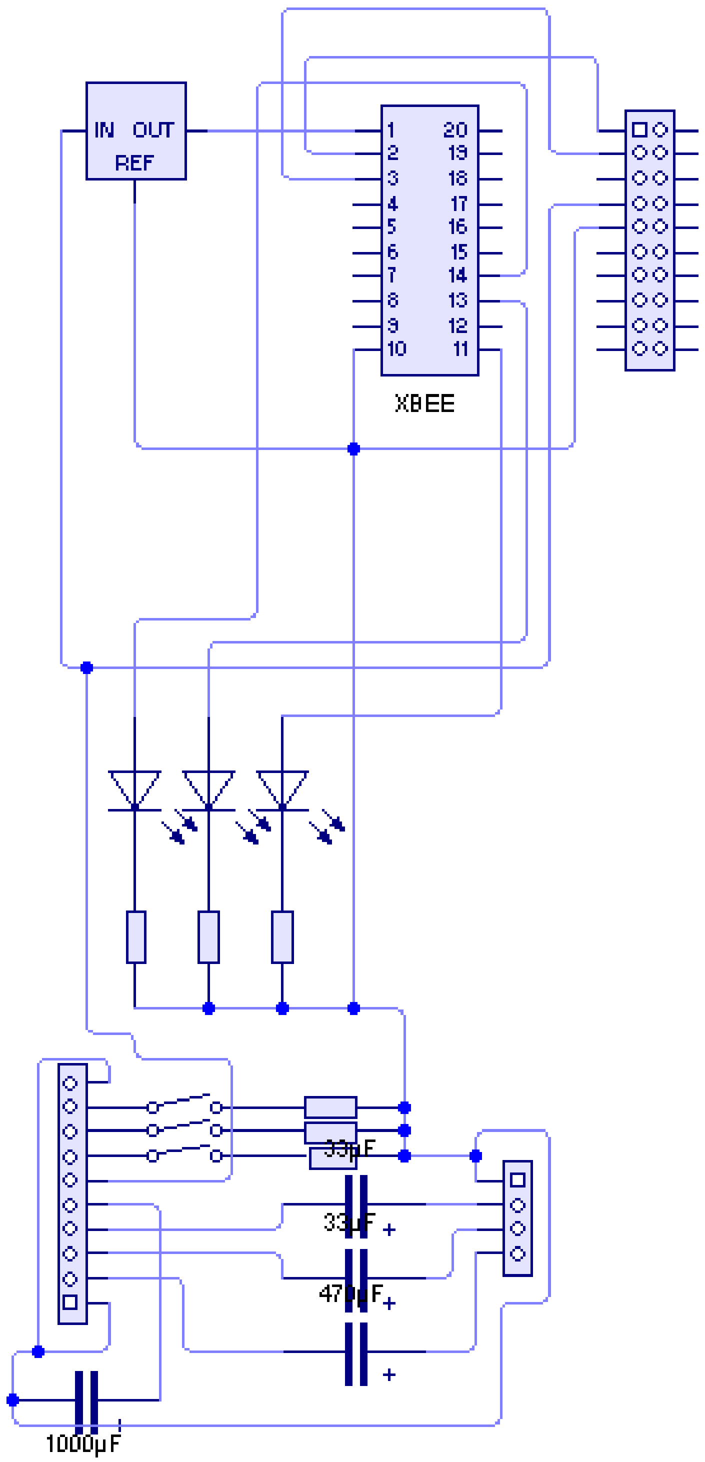


Circuit diagrams

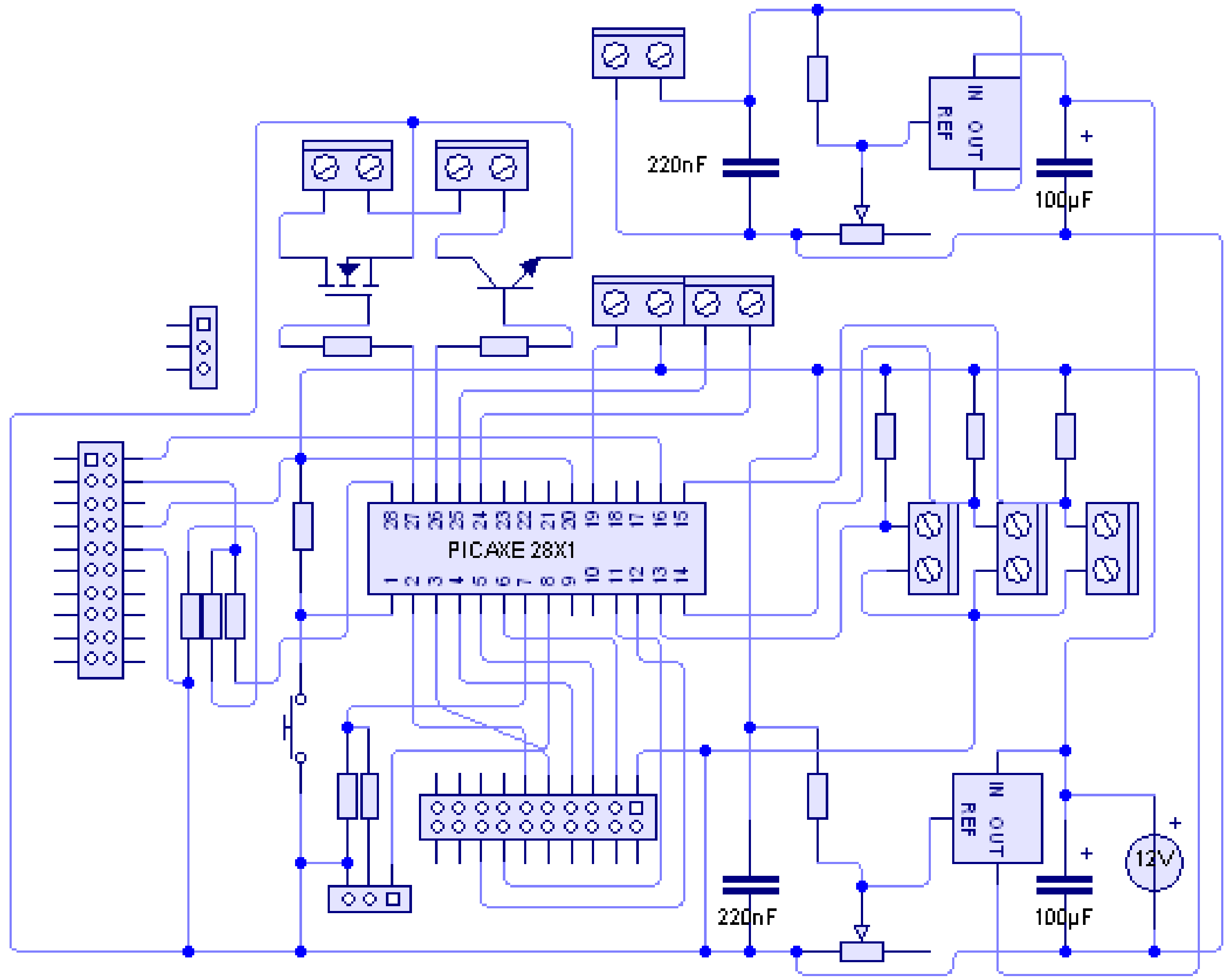
These are my schematic circuit diagrams. These schematics show how the electrical connections on my project will form.

TX Schematic

Radio schematic diagram



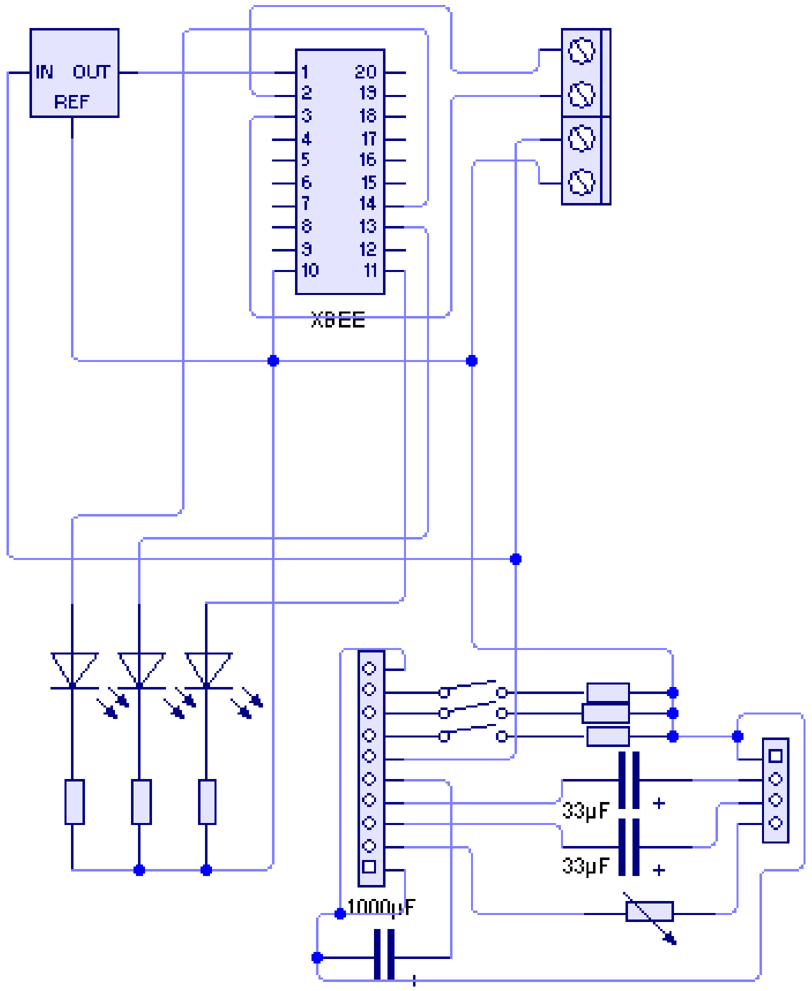
Main unit schematic



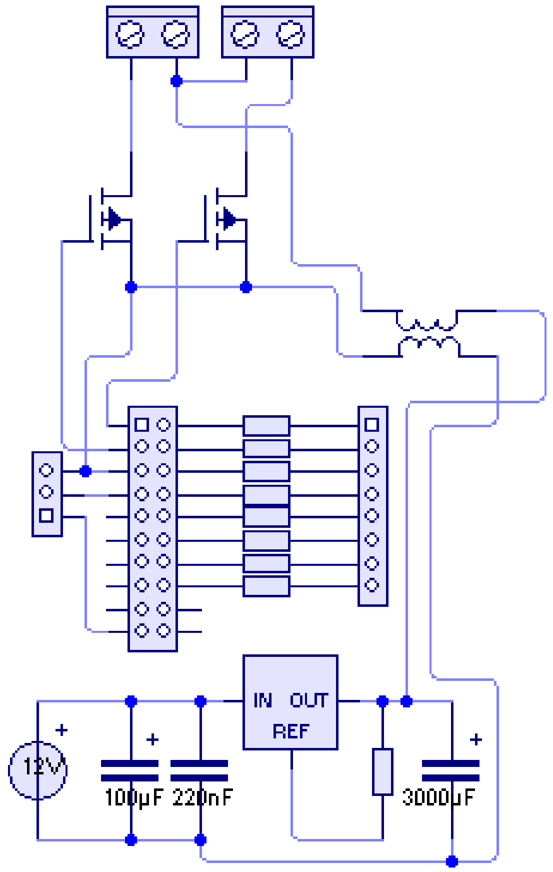
Circuit diagrams

RX Schematic

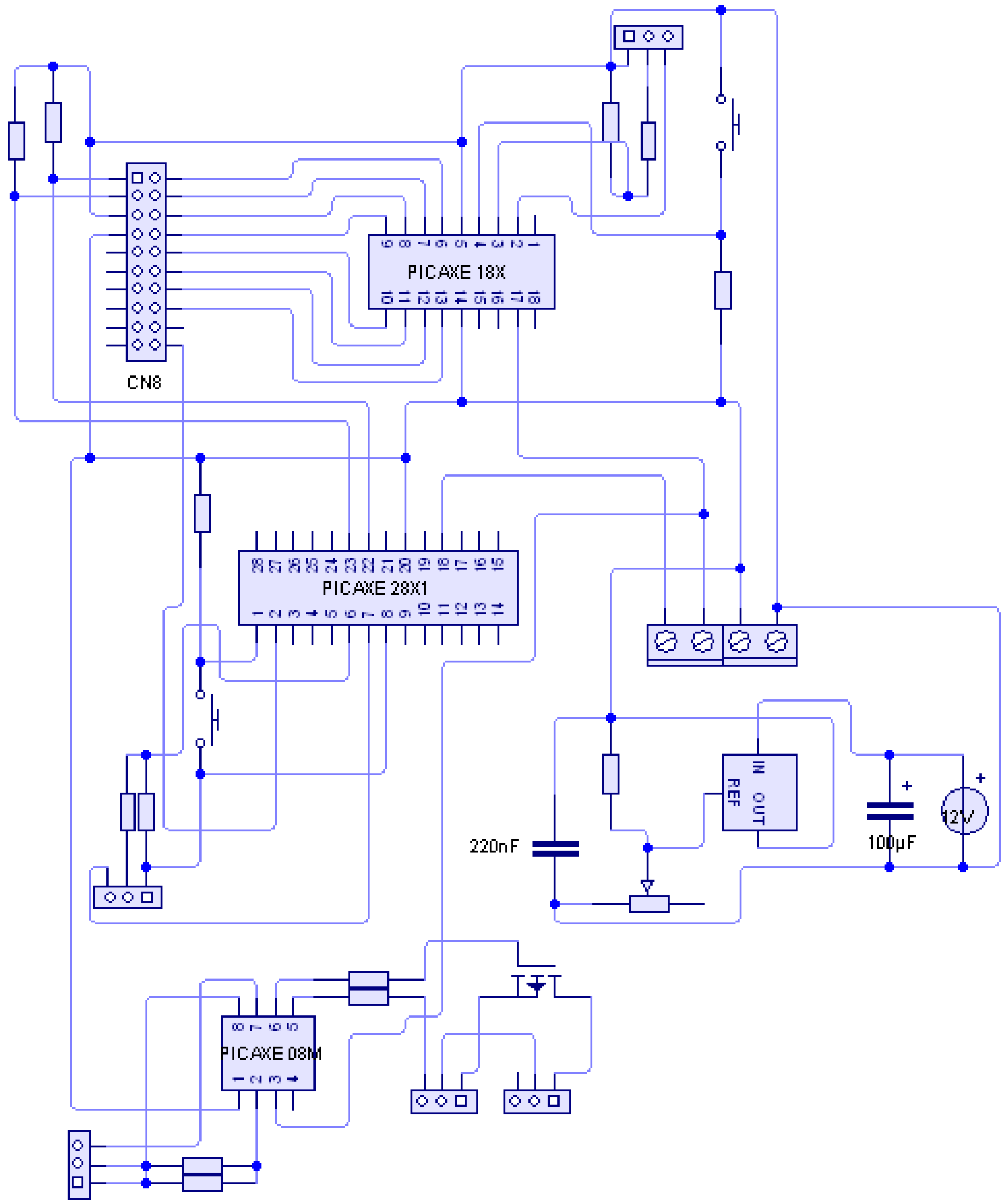
Radio schematic diagram



Servo schematic diagram



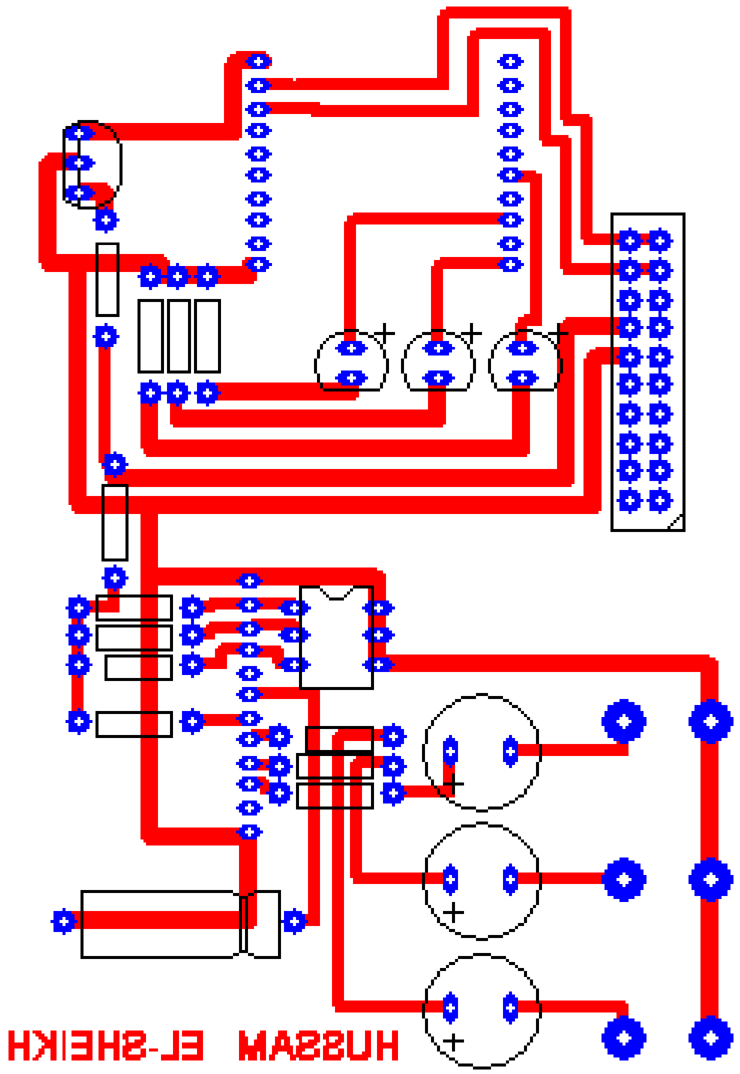
Main unit schematic



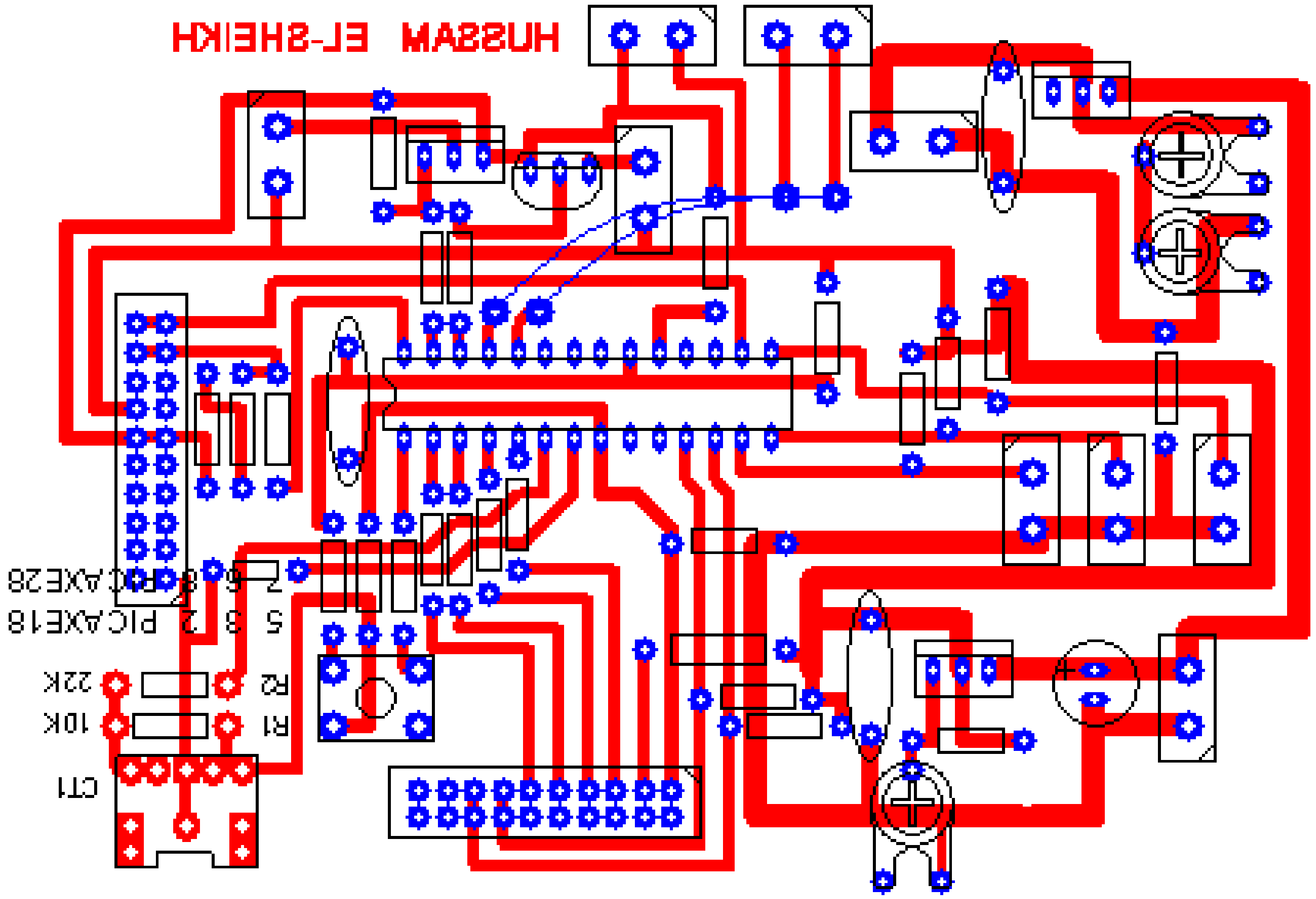
PCB Designs

To make a printed circuit board I first needed to make a PCB design. To do this I used software called PCB wizard, this is a CAD program that will allow you to make the design easily. The program has many components in its library in many standard sizes; it also has the ability to make custom component designs if it is not present. I had to do this for the DC-DC converter where I measured the space of the pins and added pads and tracks on the design accordingly.

TX Radio Board

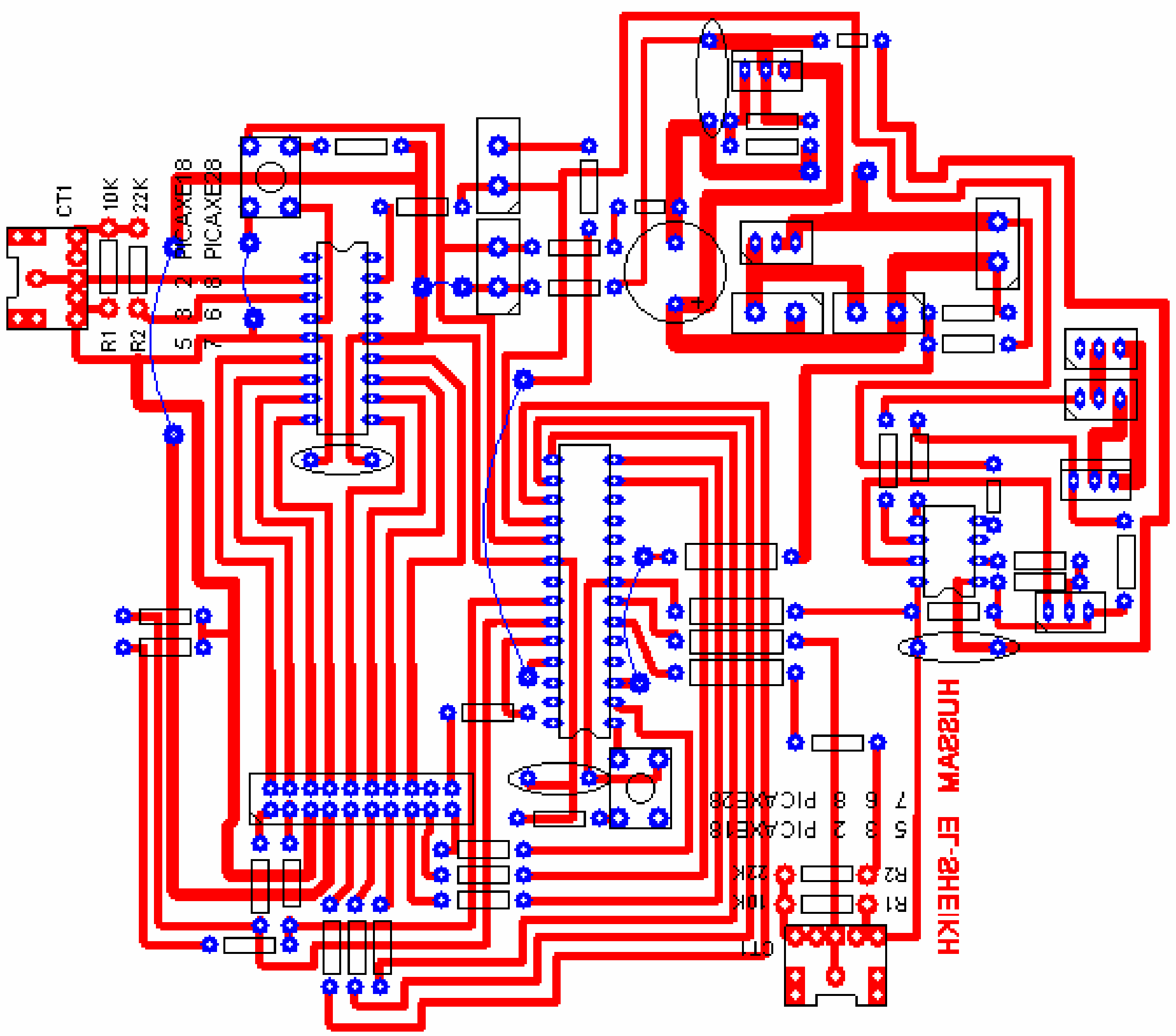


TX Control Board

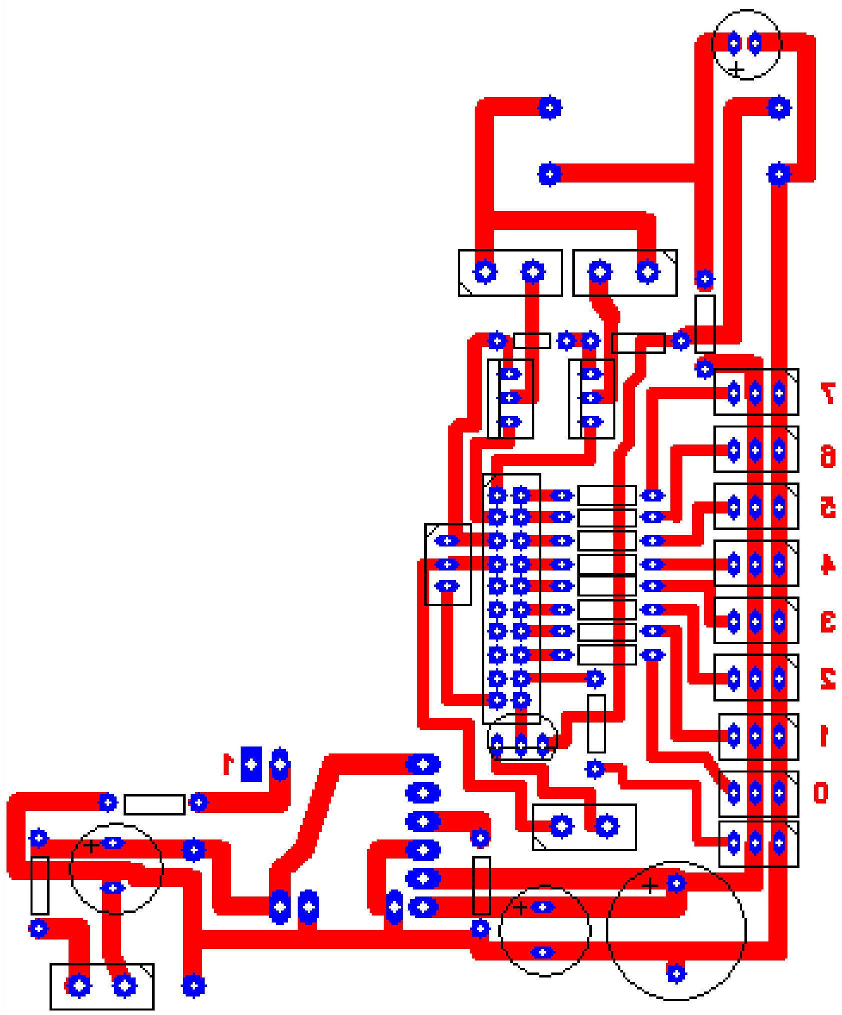


PCB Designs

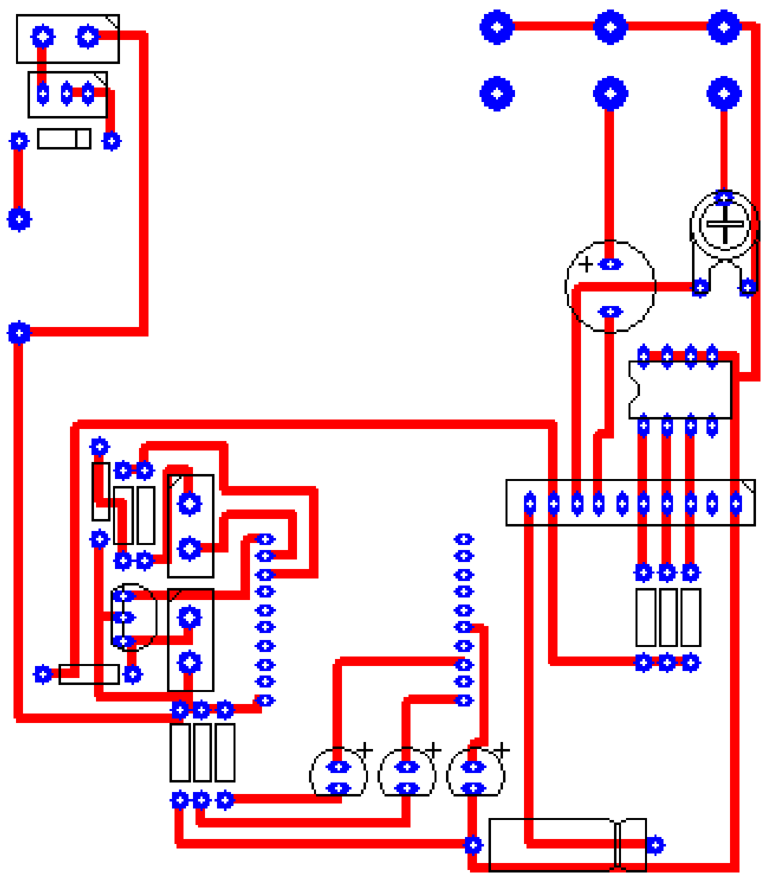
Main RX Board



Servo Board



RX Radio Board



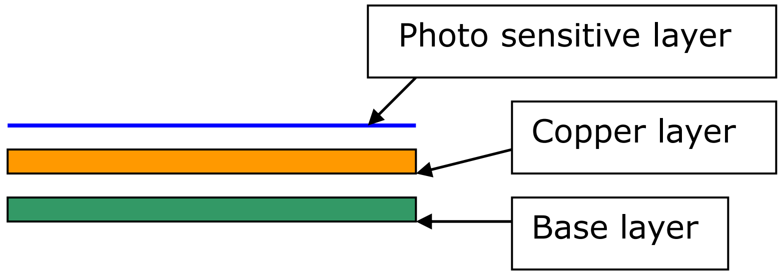
Before the PCB can be made it is important to check the PCB design for any mistakes, as it would be difficult to fix any major errors. This will also improve circuit quality.

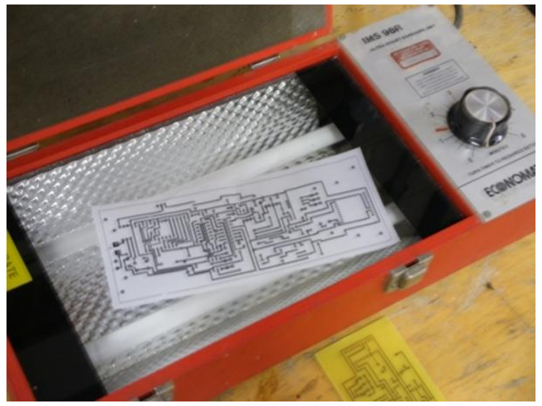
On my designs I made the tracks thicker than the default value, this will reduce the resistance in my circuit and therefore reduce power wastage in heat form, this is because power is directly proportional to current squared ($P \alpha I^2$). This was important in my servo board where there is a possible max current of 16A.

PCB Production

The method of PCB production used in the department is "photo - etch resist". Once the design of the PCB is completed a mask needs to be produced. The mask is just the pattern of tracks and pads printed on tracing paper.

The circuit board is a base that is copper clad and it has a thin photo sensitive layer on top of the copper.





PCB mask on the UV exposure box.

Order of production

1. A correctly sized sheet of the circuit board is placed in an Ultraviolet light box with the mask preventing the exposure of the track pattern.
2. The exposed board is then placed in a solution of sodium hydroxide to remove the exposed photo layer, leaving a "photo" of the unexposed track pattern.
3. This is then placed in the bubble etch tank, which contains a solution of hot ferric chloride. This solution eats away the unexposed copper leaving the tracks and pads.
4. The Board is then cleaned and drilled.

PCB Production Area

Quality control

At this stage I need to begin my quality control checks. The PCB is the first of my critical points, so to check the board all the tracks were checked for breakages and continuity using a multi metre.

A look at industry

Industrial PCB manufacture is on a much larger scale than school PCB production. On a visit to SMS electronics I saw how industrial PCB manufacture works. The plant has a massive stock of components, surface mount and through components. The circuit boards themselves are bought in from somewhere else, but once they have the board they are ready to begin the process.

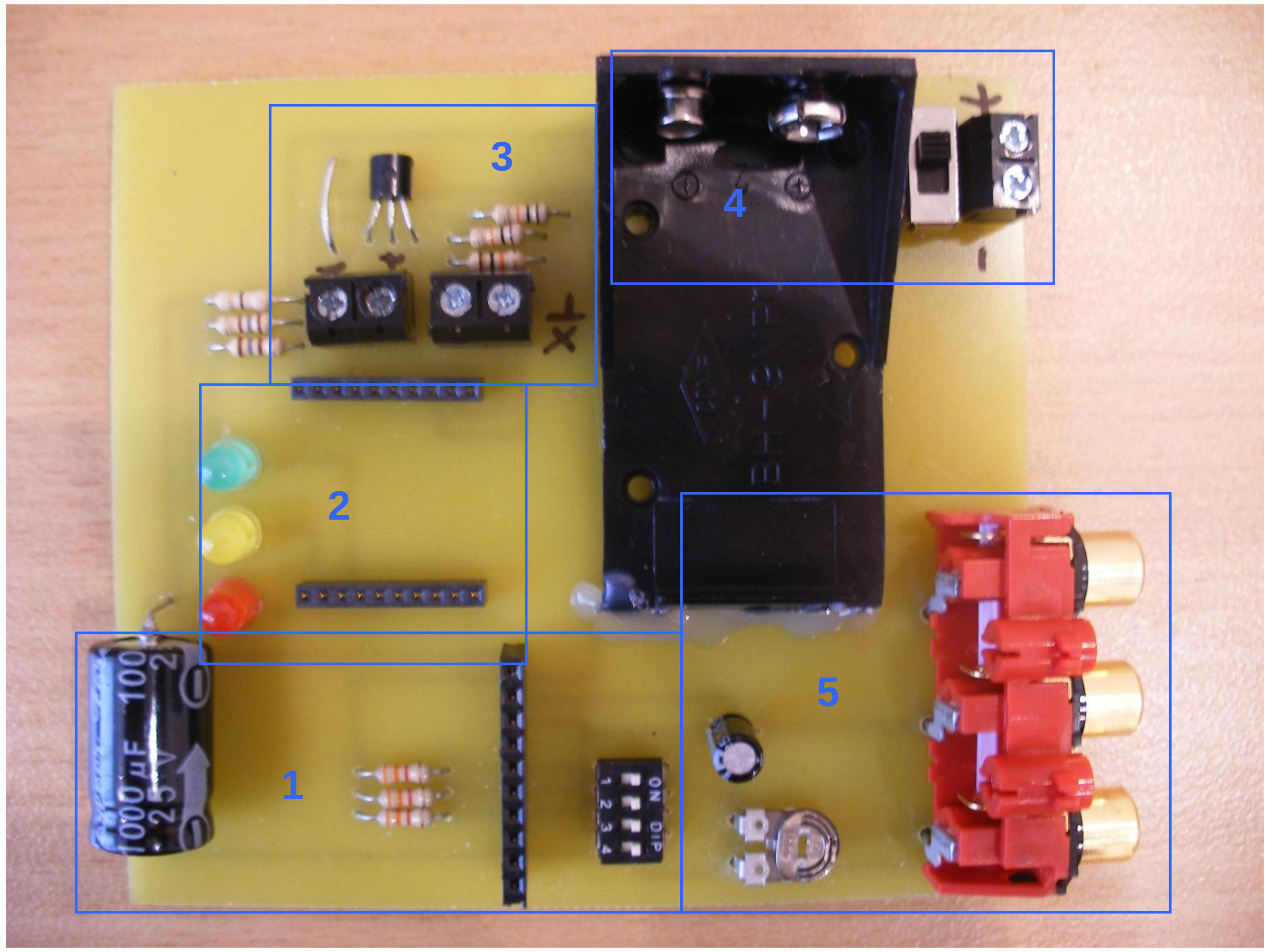
The boards are put onto pick and place machines, computerised arms pick up and place the components on the circuit board which has already has a layer of solder past on the pads, the pick and place machines are capable of placing 25,000 components per hour! Once the components are fixed the bard is put through an oven that heats up the solder on the board which then melts and makes the connection.

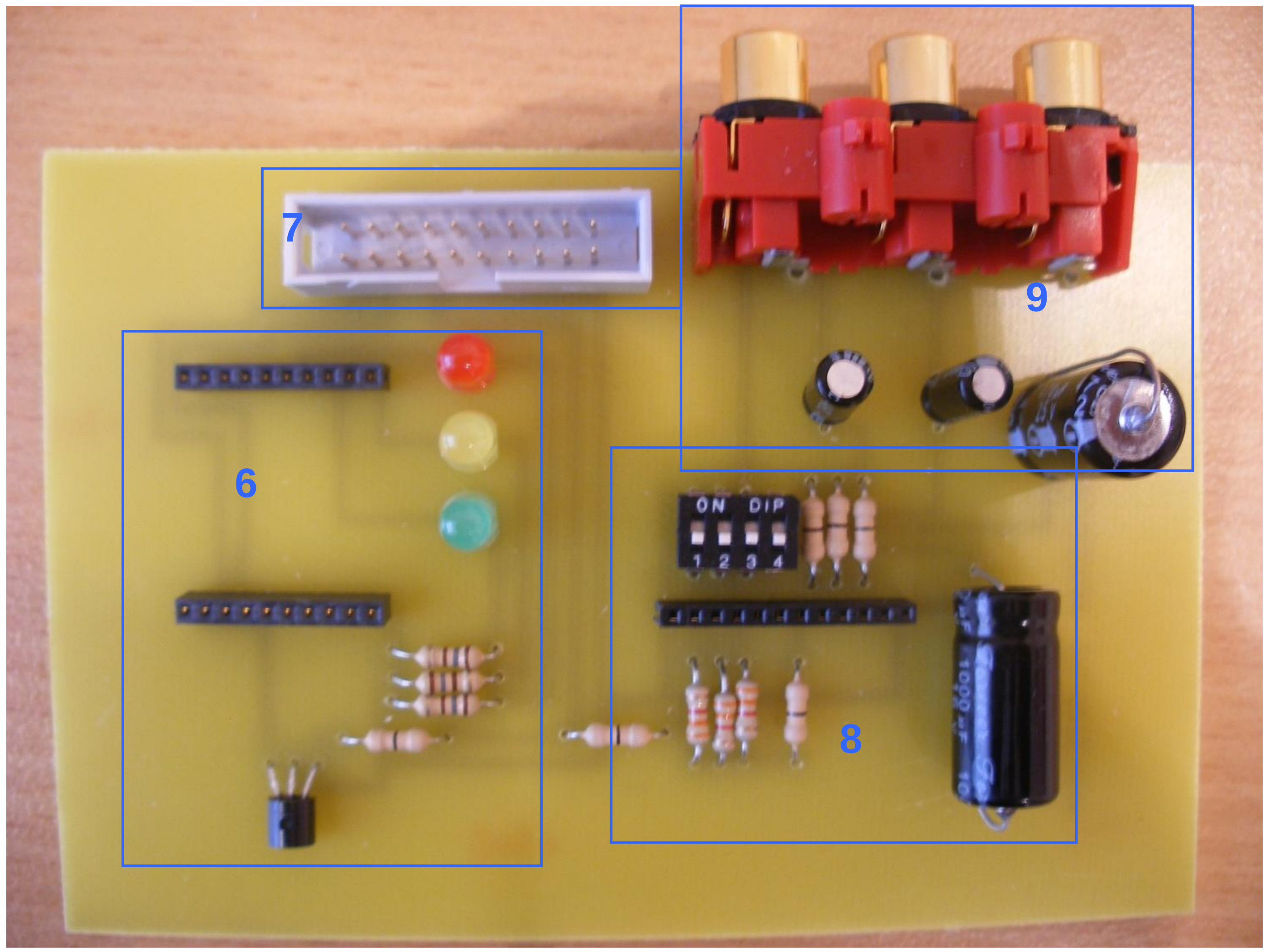
The completed boards are then subjected to meticulous quality control checks to ensure the customer gets a top quality PCB.

Circuits: Radio Boards

TX board

RX Board

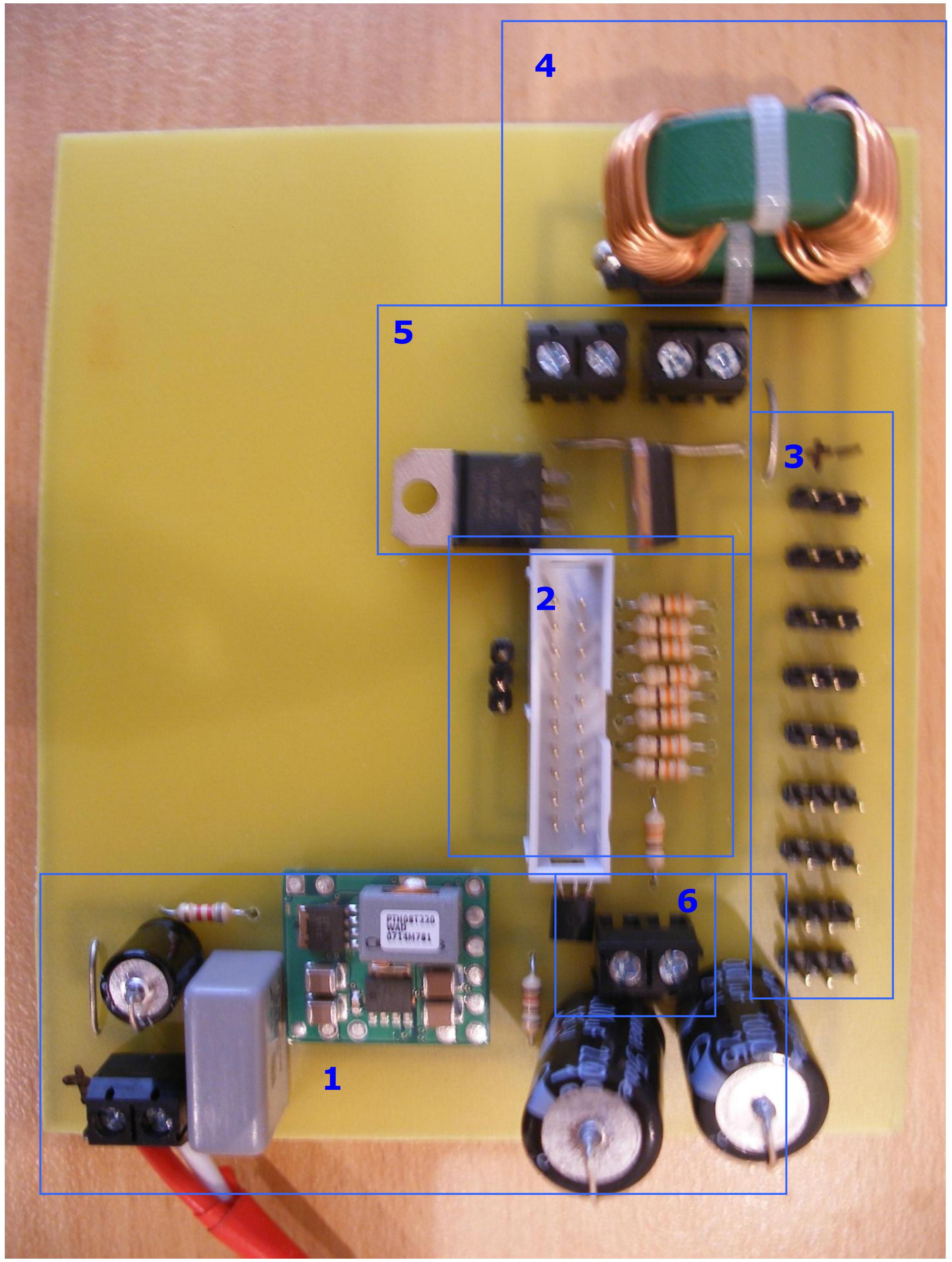




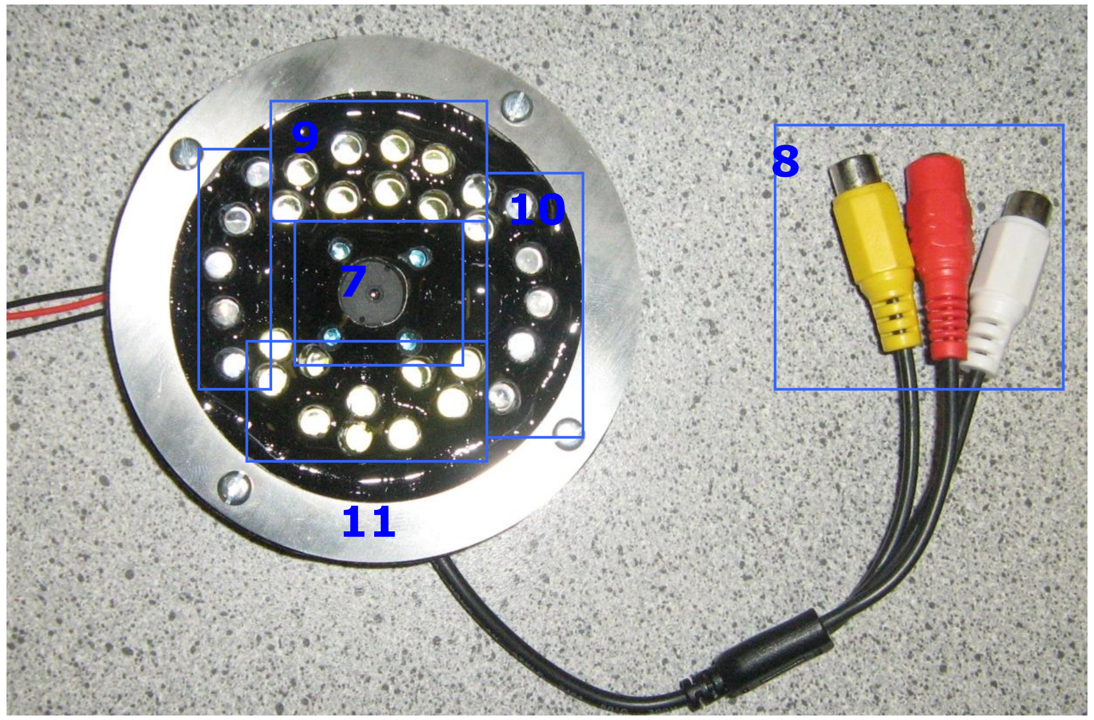
1.This is where the transmitting airwave module will be. The decoupling capacitor can be seen, along with the channel select switches.
2.XBee header pins. The XBee will transmit and receive data between PICAXE's. Also shown are 3 XBee status LED's.
3.Two, two way terminal blocks supply power to the board and the data lines for the XBee. Also there is the 3.3v regulator for the XBee.
4.9v battery slot for the camera's power supply, along with a switch and terminal block to connect to the camera.
5.Phono sockets that will input the camera's audio and video feeds. Also seen is the resistor on the video line needed to allow transmission.

6.XBee header pins. The XBee will transmit and receive data between PICAXE's. Also shown are 3 XBee status LED's and 3.3v regulator.
7.IDC connector provides power to the board and the data lines for the XBee.
8.This is where the receiving airwave module will be. The decoupling capacitor can be seen, along with the channel select switches.
9.Phono sockets that output the AV feed to a screen.

PCBs: Servo Board and Head

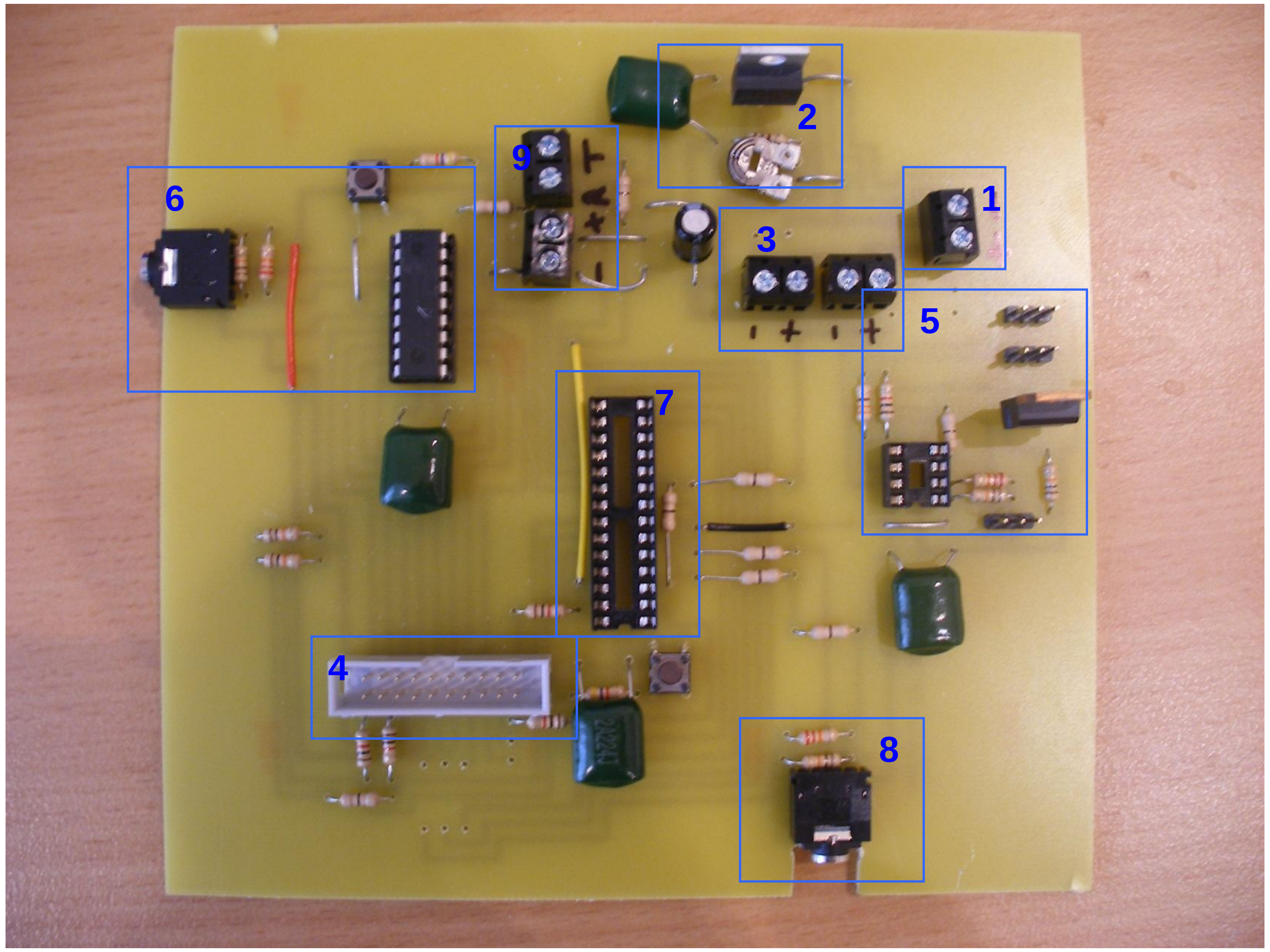


1.This is the Power module for the servos. The unit in the middle is a DC-DC converter and provides the necessary current output for the servos. Large capacitors on the output ensure a smooth power rail.
2.This IDC connector carries the servo signals from the main board to the servo board.
3.This is the column of header pins for the servos to plug into.
4.A common mode suppression coil, a type of inductor. This is in place to eliminate the electrical noise created by the servos. It works in conjunction with a capacitor behind it.
5.These terminal blocks connect to the lights on the head of the snake arm, controlled by their respective MOSFET's.
6.An extra output controlled by a transistor.



7. The camera module with its own Infra red LED's.
8. Output lines of the camera, Video, Power and audio (left to right).
9. 20 ultra bright white LED's top and bottom.
10. 10 Infra red LED's.
11. Stainless steel ring to hold the HIPS cover on the PCB.

Circuits: Main Board



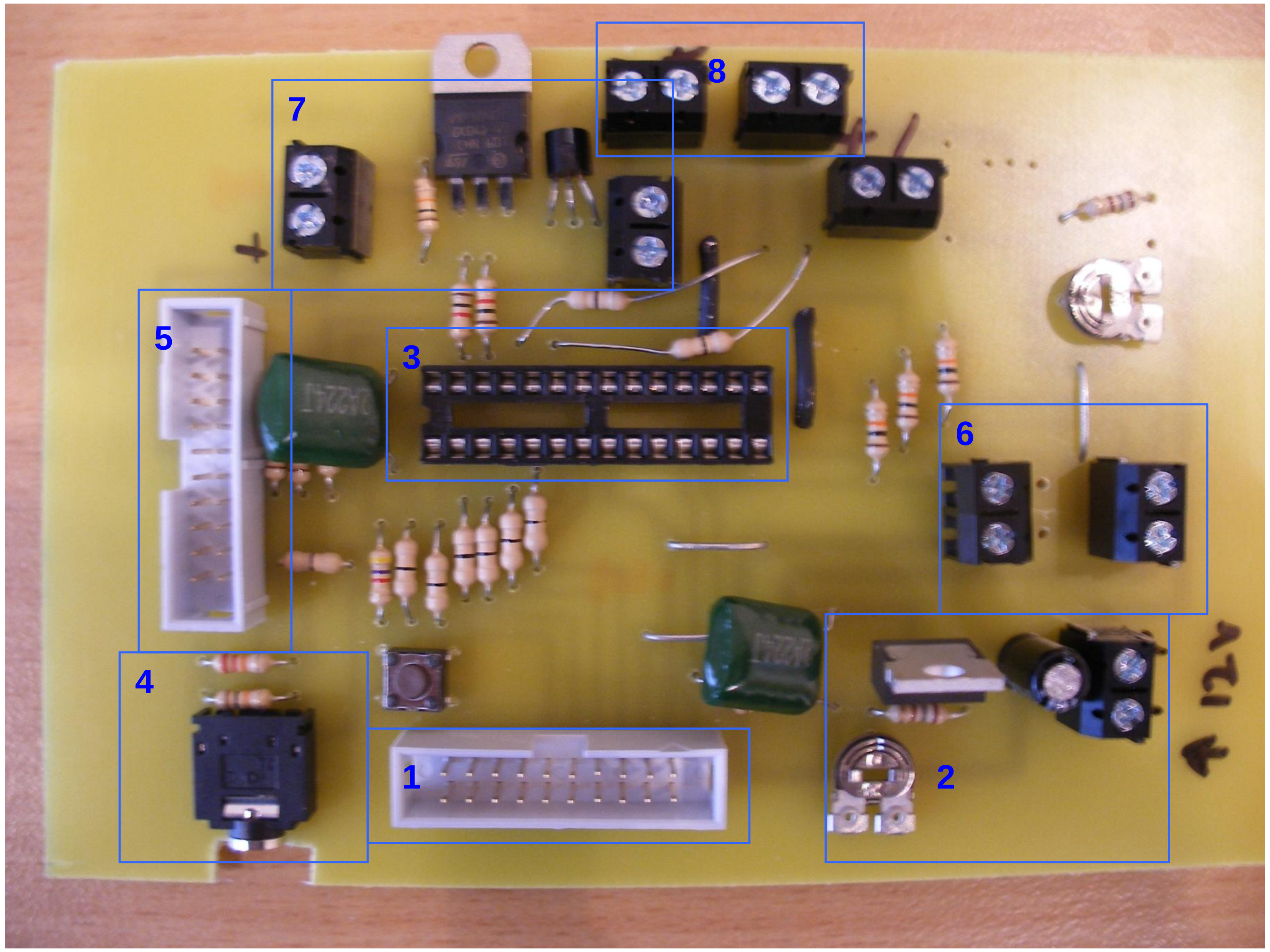
1. 12V input for the board.
2. 5V regulator for logic.
3. Other 12V extension points.
4. IDC connector. This carries all the servo signals to the servo board.
5. PICAXE 08M. This PICAXE controls the lifting servo, using a serin line from the XBee.
6. PICAXE 18X. This generates all the pulses for the servos and its download socket.
7. PICAXE 28X1. This responds to a serin line from the XBee and controls the 18X and rest of the outputs.
8. Download socket for 28X1.
9. Power and data lines for XBee and RX board.

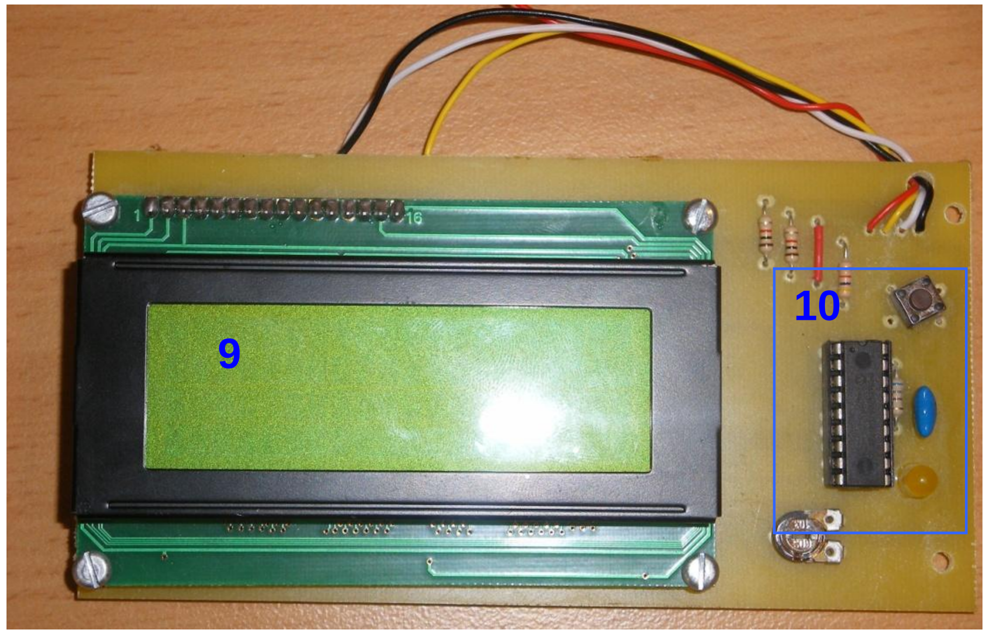
10. 3 line communication between 18X and 28X1.

This PCB had to be adapted when it was discovered that the servo command does not function correctly with the serin commands. The new edition of the PICAXE data sheets has this information about the servo command, but the older ones did not.

The initial set up was the 18X controlling the servos, acting on data it received via serial from the XBee. This however caused the servo pulses to be temporarily stopped whenever the 18X checked for serial. This then meant that the servo would not support tension for the periods when the command was stopped. To solve this problem I allowed the 28X1 to receive the serial data for the servos, and then I added on a 3 line link between the 28X1 and 18X. I would use this 3 line communication as a binary system. So instead of the 18X acting on a serial signal it would at upon the state of these 3 pins. This meant that the servo command remains uninterrupted and the servos never lost their position pulse.

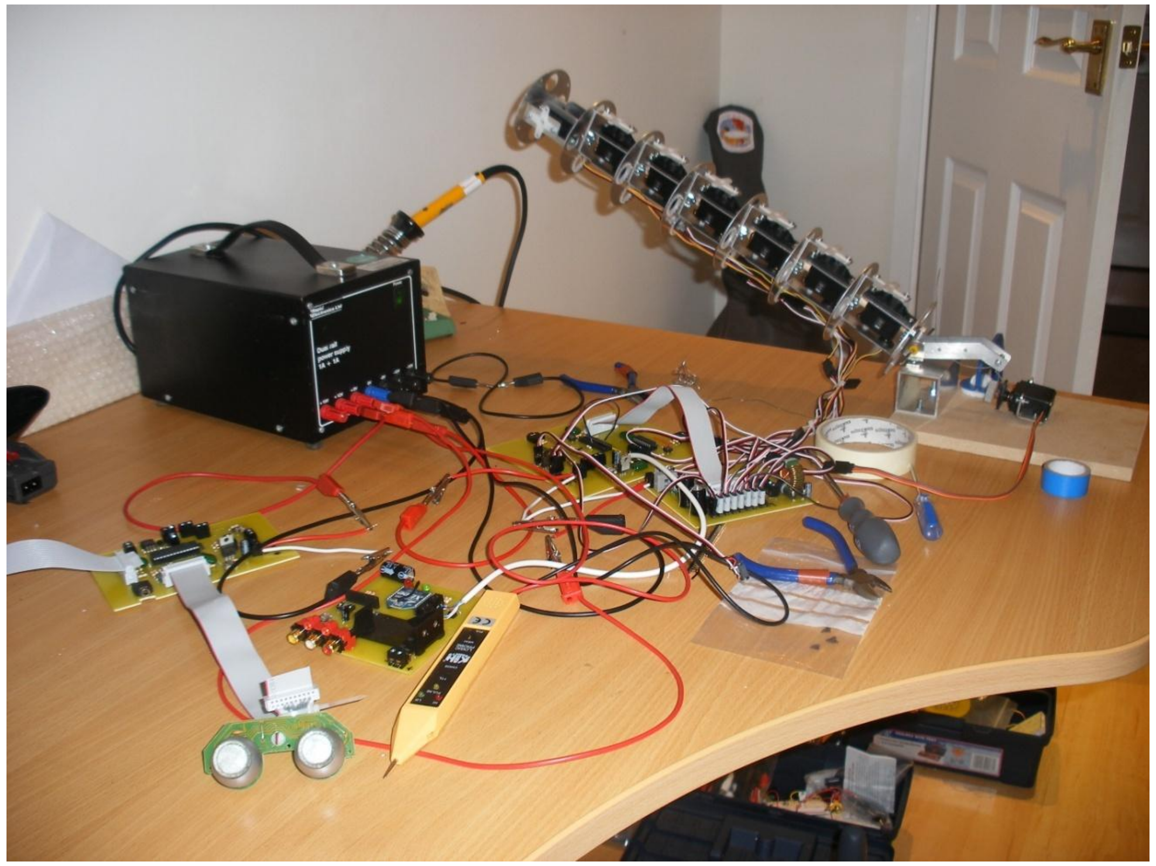
Circuits: Control Board





1.IDC connector to the controller, this then connects to the ADC pins of the PICAXE.
2.Voltage regulator, supplies 5v to the board.
3.PICAXE 28X1.
4.Download for PICAXE.
5. IDC connects to the RX board, carries the power and XBee data lines.
6.Inputs for additional controls.
7.Free additional outputs.
8.LCD connection.
9.20x4 LCD.
10. LCD firmware IC.
11. Joystick for snake body movement.
12. Joystick for snake head movement.
13. Toggle switch to enter/exit menu mode.

Preliminary Testing



At the stage where I have the robot body built and the circuit boards completed I needed to do a test. Because my project has so many components I had to see how the all worked together before I conduct my final testing and evaluation. I had tested all of the separate components and they had worked, however I needed to see that controlling the snake by the joysticks worked effectively, and that it could work across the radio link.

In the picture the assembled snake arm can be seen lifted at a pivot point. The arm has a significant moment, and by experimentation I discovered that 4Kg was needed at the end of the arm to lift the arm. To achieve this power an adapted high torque servo was used (details below).

This test was a success, the arm lifted, and the servos were controlled by the analogue sticks. The whole system worked very well over the XBee network.

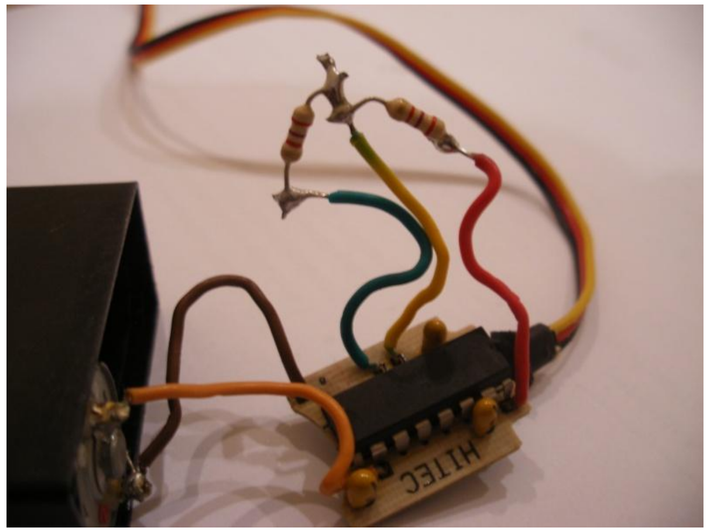
MG995

The servo I chose for the lifting job was the "TowerPro MG995", this is a servo with 13Kg/cm of torque. The MG995 has all metal gears with dual ball bearings, combined with a powerful motor this is what produces the huge forces.

However this servo needed to be adapted before it can be used. The servo needed to be converted to rotate continuously. I first removed the physical stopper which is the metal pin on the output gear. Next I removed the position potentiometer; this meant that it now had no feedback of where it was. To fix this I needed to create a false position. The 3 wires that were connected to the pot now have two identical resistors soldered on it this splits the voltage in half; this therefore fixes the position as always in the centre.

No if I were to give a pulse of 75ms it would keep on rotating because it will not be able to find that position because it thinks its at the centre.

Inside the servo



Case manufacture

Vacuum Forming is a process where sheet of plastic is heated to a forming temperature, stretched onto or into a single-surface mould, and held against the mould by applying vacuum between the mould surface and the sheet. The plastic used is HIPS; High Impact Polystyrene.

Here is the mould I used for the case. It was created by first making a big block of wood to work with; this was done by layering sheets of MDF and gluing them together with PVA wood glue.
Once the glue has dried, the block is ready to be shaped; using a band saw the block was cut into shape, and profiled to the LCD screen will fit on the back of it. Then with wood tools I worked it until it was a smooth all-round surface.
The surface must be very smooth so using fine M2 grade sandpaper; I went over the whole mould to make it as smooth as possible.

Also to make the process of making a base easier an acrylic sheet was secured between the bottom two layers. This meant that the plastic would be shaped so that it fitted perfectly with the base once it was removed.

Here I am moulding my first attempt at the RX case before changing the design. I had already placed the mould inside the machine and then clamped a piece of HIPS plastic on top of it and then began to heat it with the heater. Once the plastic was heated until its plastic state it was ready to be moulded.
I lifted the mould up and switched on the pump, this sucked the plastic over the mould creating the case.
After it had cooled down, however still wearing protective gloves I removed the mould from the HIPS and cut out the case from the excess plastic.

Quality control

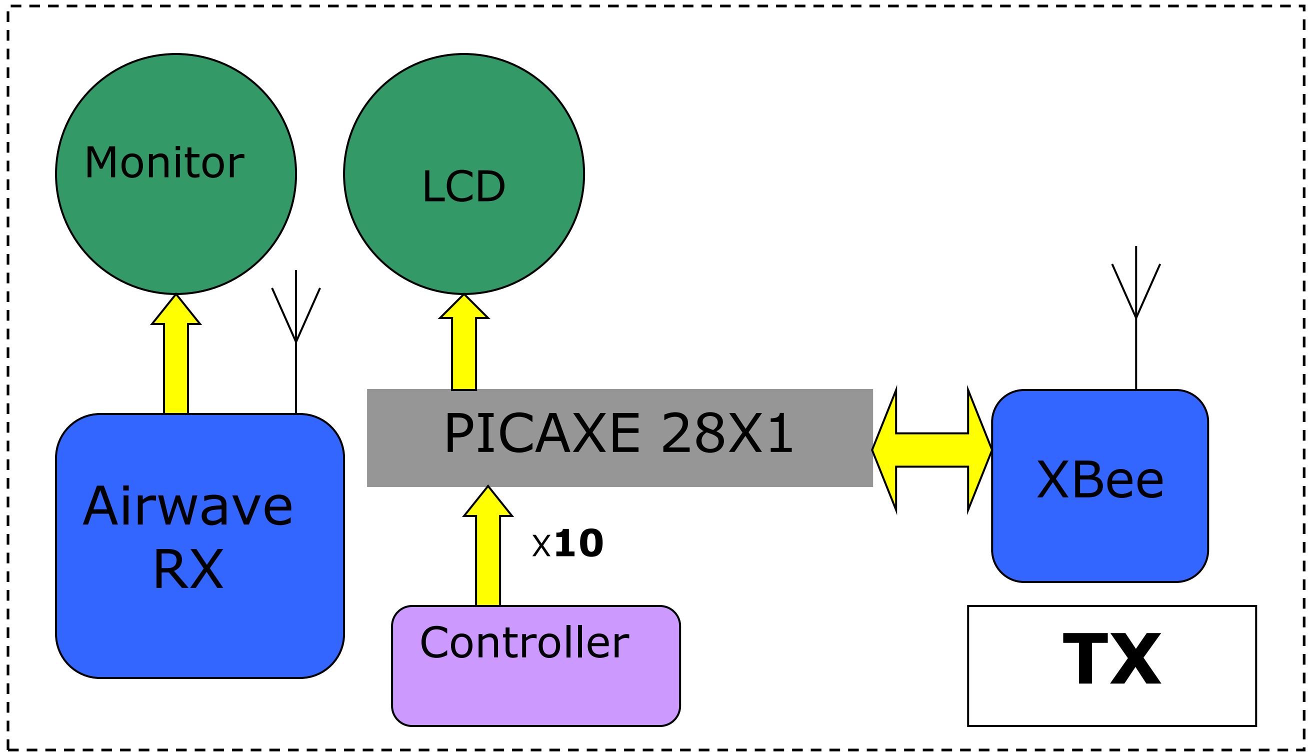
Whenever a manufacturing process is occurring constant quality control is needed, especially in this case where it's being made by hand where mistakes could occur.

- The wooden mould needs to have a minimum draft angle of 3 degrees; this is to allow the mould to easily be released from the case.
- When heating the HIPS, take care as over heating will cause webbing on the corners of the formed plastic.
- Also the HIPS needs to be dry as any moisture present could expand and create bubbles.
- When tapping a 2.5mm pilot hole is needed. Initiate tapping with a tapered tap then go onto the parallel tap for a good cut.
- Secure the acrylic with a G –clamp to give a secure bond, and to maintain its position.

Once the case was out I could now begin to fit it out. The first jobs to do were to cut out any holes needed before the bottom was fitted. This was because if the holes were incorrect then the mould would still be intact to make another. I used a dremel tool to cut out the hole for the LCD on the top surface, having already measured it using a vernier to keep accuracy. Then on the back I cut holes for the Ps1 screen to fit. As can be seen all the holes are straight and the screen fits very well.

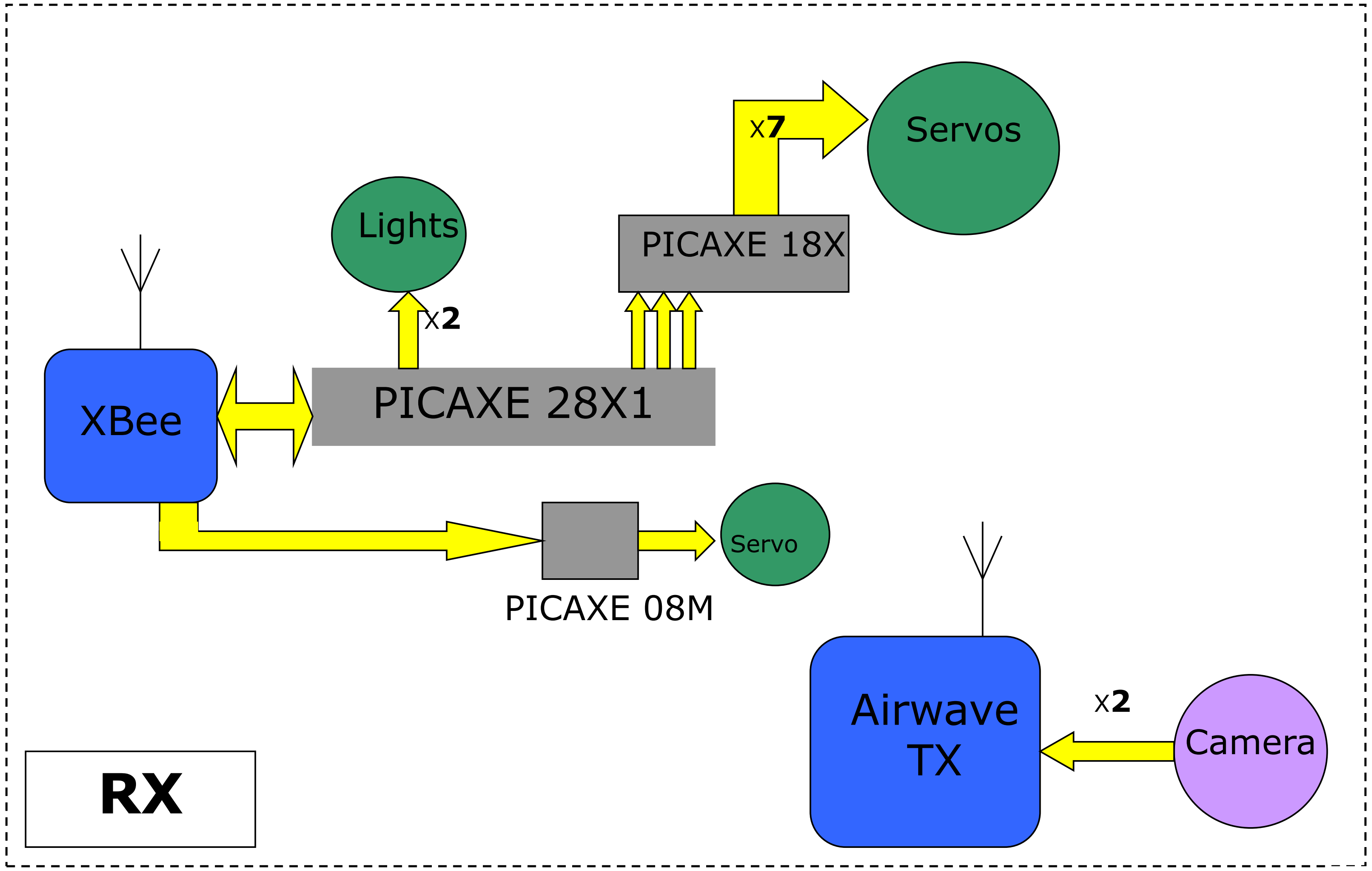
When it came time to fit the base, it was first removed by splitting the mould. As planned it fitted perfectly with the case. The base would be fastened using 3 machine screws that fasten into acrylic blocks on the inside of the case. These blocks were cut to size and tapped using an M3 tap. To ensure that the holes lined up the blocks were screwed into the base, then tensol12 solvent glue was applied to the side being fixed to the inside of the case. Then the base was put on, this meant that when the glue set all the holes would be aligned.

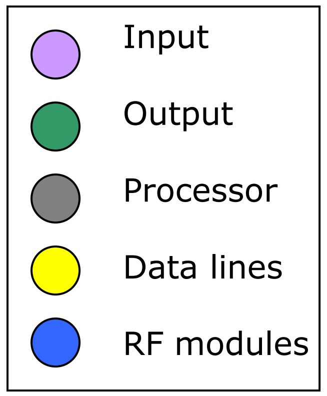
Systems Overview



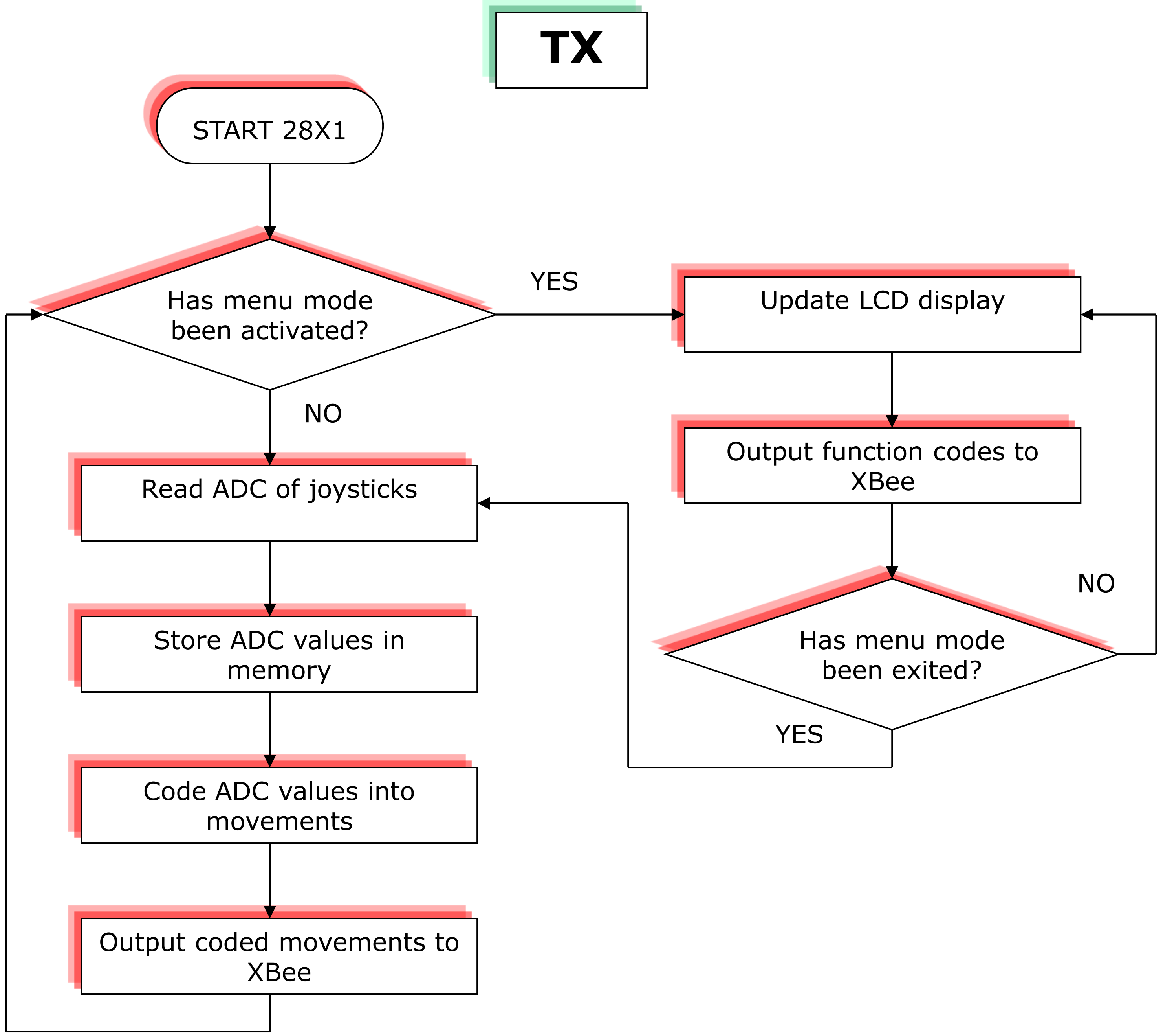
This is a basic overview of how the systems function in my project. This diagram shows the architecture between the processors, inputs and outputs, and how they communicate between each other. The data line arrows show the number of data lines between each module and its direction.

The system is based around data communication between the controller TX and receiver RX via the XBee. The XBee modules however are both TX and RX so it is not a one way RF link. Also the airwave modules handle the AV transmission; these are a one way system because it is just continually transmitting the AV signals from the camera to the monitor.



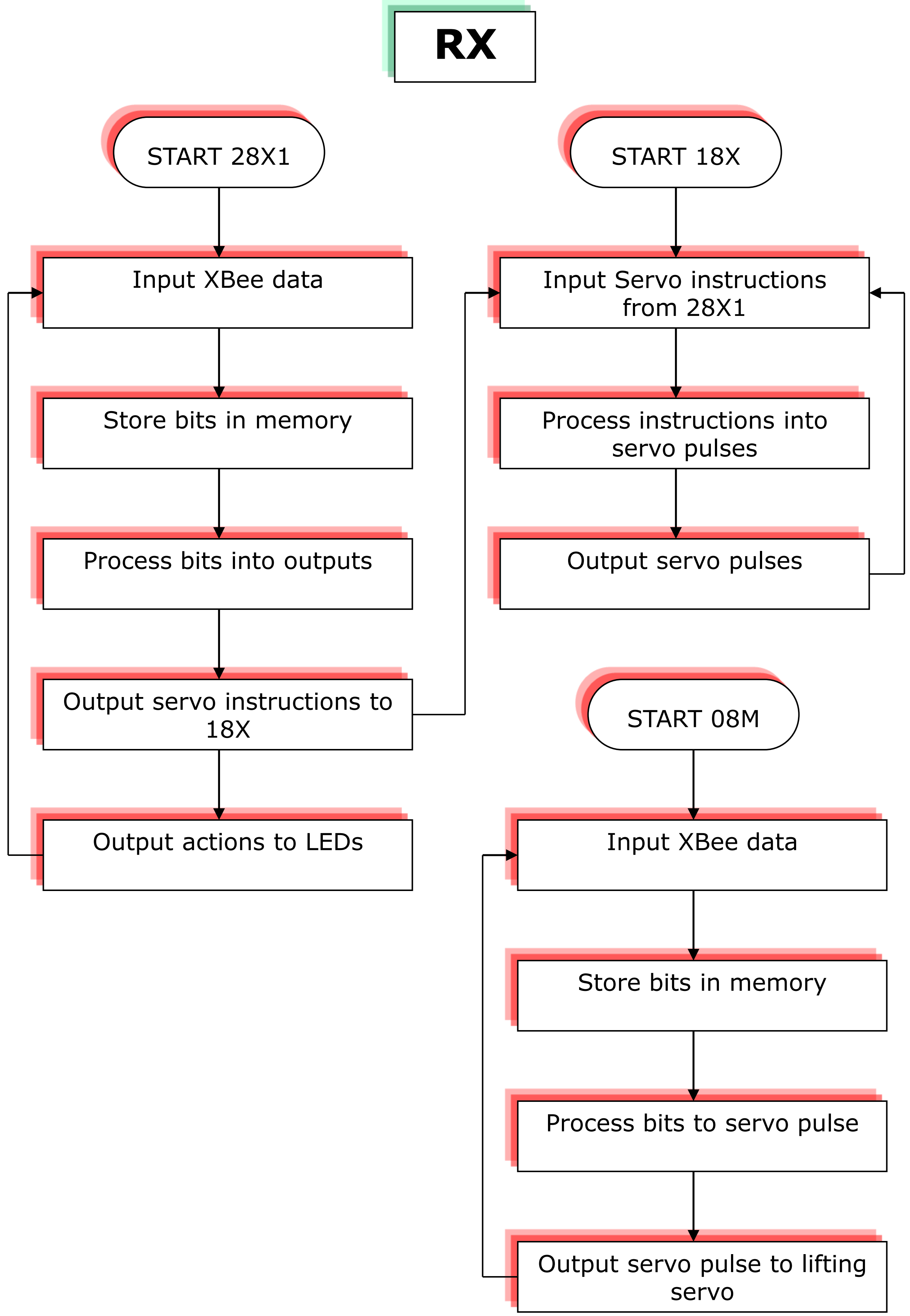


Process Flowchart



These flowcharts are an easy way to illustrate what my program is doing. Rather than explaining each command which would not be very easy to follow or write, I have used the flowchart to simplify each process step in my program.

My program is not very complex and uses the "basic" PICAXE commands. A full print out of all my programs can be found in the appendix.



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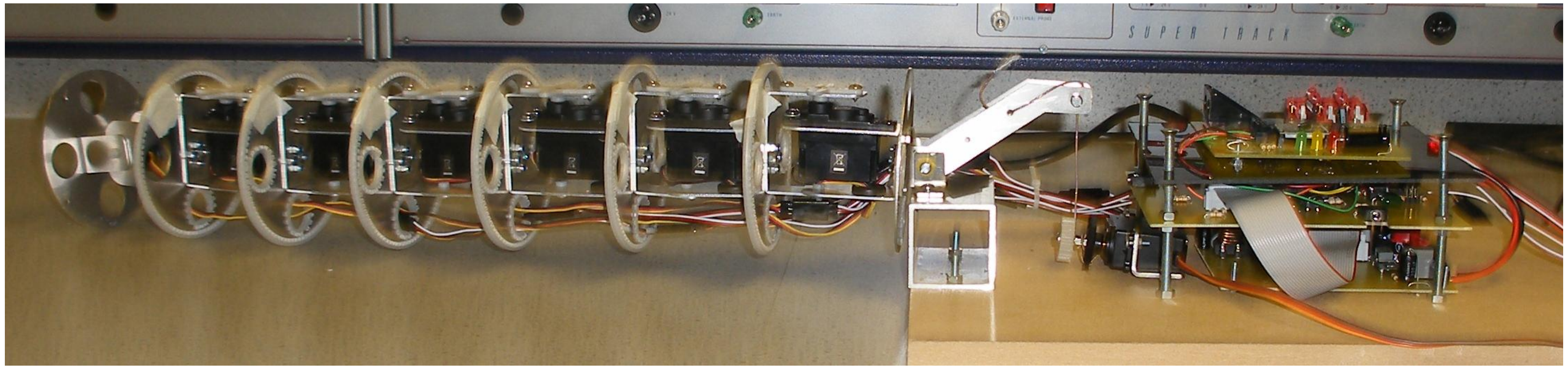
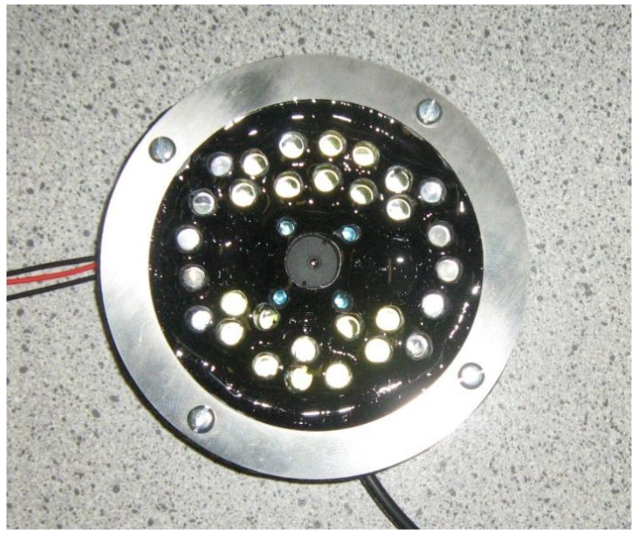
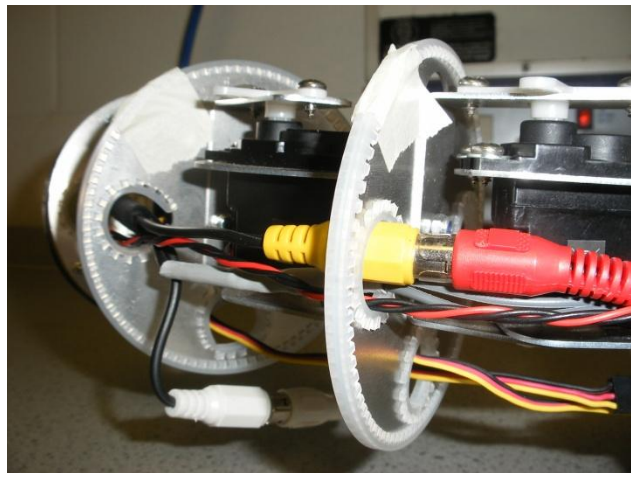
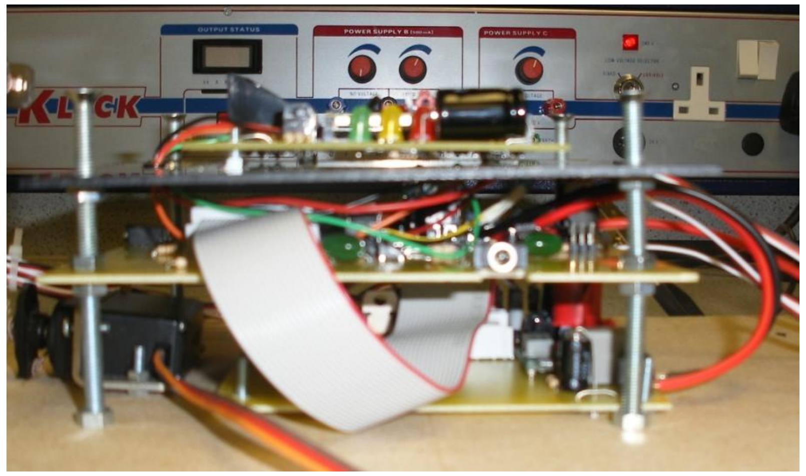








This is the camera unit; behind the vacuum moulded cover is a colour and night vision camera. Around the camera are 20 ultra bright white LEDs and 10 ultra bright infra red LEDs. The whole unit is held in place is held together by the stainless steel ring around the outside, this is also the method by which the unit is bolted onto the front servo module.

In between each servo unit is a round aluminium plate. This plate has four holes around its surface. These holes allow all the wires to pass down the length of the snake. The edge of the holes, along with the rim of the round plate is covered by plastic grommets. The grommets protect the wires and people from the sharp edges of the metal.

The entire arm pivots around the base. The arm it attached to a heavy duty pivot arm, which is made from 1.6mm stainless steel to support the tension. Running from the end of the arm to the lifting servo is a wire wound cord with a nylon core. This is a very strong cord to support the tension. The lifting servo is an adapted metal gear servo. The servo was adapted to turn continuously and it has 13Kg of torque. This amount of force was needed to lift the entire arm up.

The circuitry for SnakeBot is arranged as a tower to reduce its area. On the bottom is the servo board, the middle is the main processing board and the top is the radio communication board.

Testing

When testing a product, the aim is to find out to what degree the product fulfils all of the points on the specification that lead to its creation.

For my testing I will be testing against the original specification, and also getting others to judge other aspects such as the usability.

- The arm is a snake design; this is achieved by having the modular servo sections.
- This is arm is designed to work remotely away from humans, however when handling the arm it needed to be safe. The circuitry is covered up so nothing can short circuit and make a fire, the sharp metal edges that are exposed are protected by plastic grommets and the individual can't trap fingers due to the stop I placed in the software.
- I feel the arm is very simple to use. The familiar layout of a game joystick makes people who use it immediately comfortable. The pad only has 3 inputs to control the entire arm making it very simple. The shape of the pad is very ergonomic and fits into any ones hands. I felt also that the control response was too slow, but adequate.
- The circuitry is very reliable; I conducted a stamina test in which I left it on for long periods, followed by bursts of heavy electrical load. The electronics functioned correctly throughout this test. The components I used were of the highest quality and met all industry standards, also because of the quality control at my PCB stage the PCB's were of very high quality.
- The camera on the end on the arm is colour and infra red. It successfully transmits using the airwave modules to a LCD monitor. There are quality issues with the airwave modules due to being analogue.
- The arm has a very wide range of movements. The head is controlled separately and is capable of pan and tilt motions on its own, if the other servos are engaged it can look 180 degrees. Because the servos step they can be halted at any point in their travel giving many position combinations.
- The arm works over the wireless network.
- The arm is defiantly small compared to other snake robots, the circuitry is large because of the PCB technology we have in school. Thanks to its aluminium pieces it is light, however due to the moment at the end of the arm the base servo takes a lot of tension and begins to make the arm sag.
- To add or subtract modules it is a matter of removing 5 screws and then attaching another unit. This system worked adequately, the modules would sometimes not come of the bolts and it would be difficult to tighten the screws again.
- Each segment is £8 in parts, this is very cheap for what technology is delivers. The maintenance is virtually non-existent, because the servos are self contained their gear train needs no further lubrication or maintenance, also I have used nylon between moving metal parts to reduce wear and friction significantly.
- The arm requires no assembly in-between uses. It packs away neatly, and when it is powered up the servos self centre themselves and then you are ready to use it.
- The arm can easily run from a 1A supply, so it will run on any batteries that are capable of this output. I have been successful with running them from a 12V (1.2Vx10cells) 2000mAh Hi-MH source.

Final Specification

- The robot arm will be a "Snake" design.
- The arm must be safe to use and be around.
- The arm needs to be relatively simple to use.
- The electronic control units must be robust and reliable.
- The arm will have a camera on the end for feedback.
- The arm must be highly versatile.
- The arm will be capable of being wirelessly controlled.
- The arm must be tough.
- The arm must be light.
- The arm needs to be small.
- The arm will be easy and simple to add and subtract modules from.
- The arm must be comparatively dirt cheap to buy and have low maintenance.
- The arm must be quick to set up.
- The arm must be able to use batteries for power.

User views

From asking 5 people to use SnakeBot for 2minuits I gathered information on its usability. The feedback was good; all of the 5 took to the controls very well after just being told how to use it once. They were impressed with how SnakeBot worked and what it could do. A general comment however was that the camera picture could be improved and also they wanted a 2 direction module i.e. each module can move in x and y.

When I briefly contacted Stephen Bridges again with pictures of my project he was impressed by the quality of my build. He also commented that at my current costs my arm would have a market, below the large expensive OC robotics bots. I will hopefully be able to get some video of my robot to Mr Bridges so I can get more detailed feedback from him. Also I will be contacting OC robotics to pursue my idea further with them, as they are industry leaders.

Quality control

Thanks to the quality control points through the manufacturing process, the final product is of high quality and finish.
This aspect of my project is close to industry, in that they too employ the use of critical points throughout the manufacturing process to check the quality.

Costs

This project was relatively expansive to develop. This was inevitable due to the nature of my project, I was helped immensely by my Arkwright Scholarship, and this gave me the freedom to develop a prototype that I am very happy with.

The most expensive single purchase was my laser cut parts which cost £130, however the project would not have succeeded to the same degree if they had not been used.

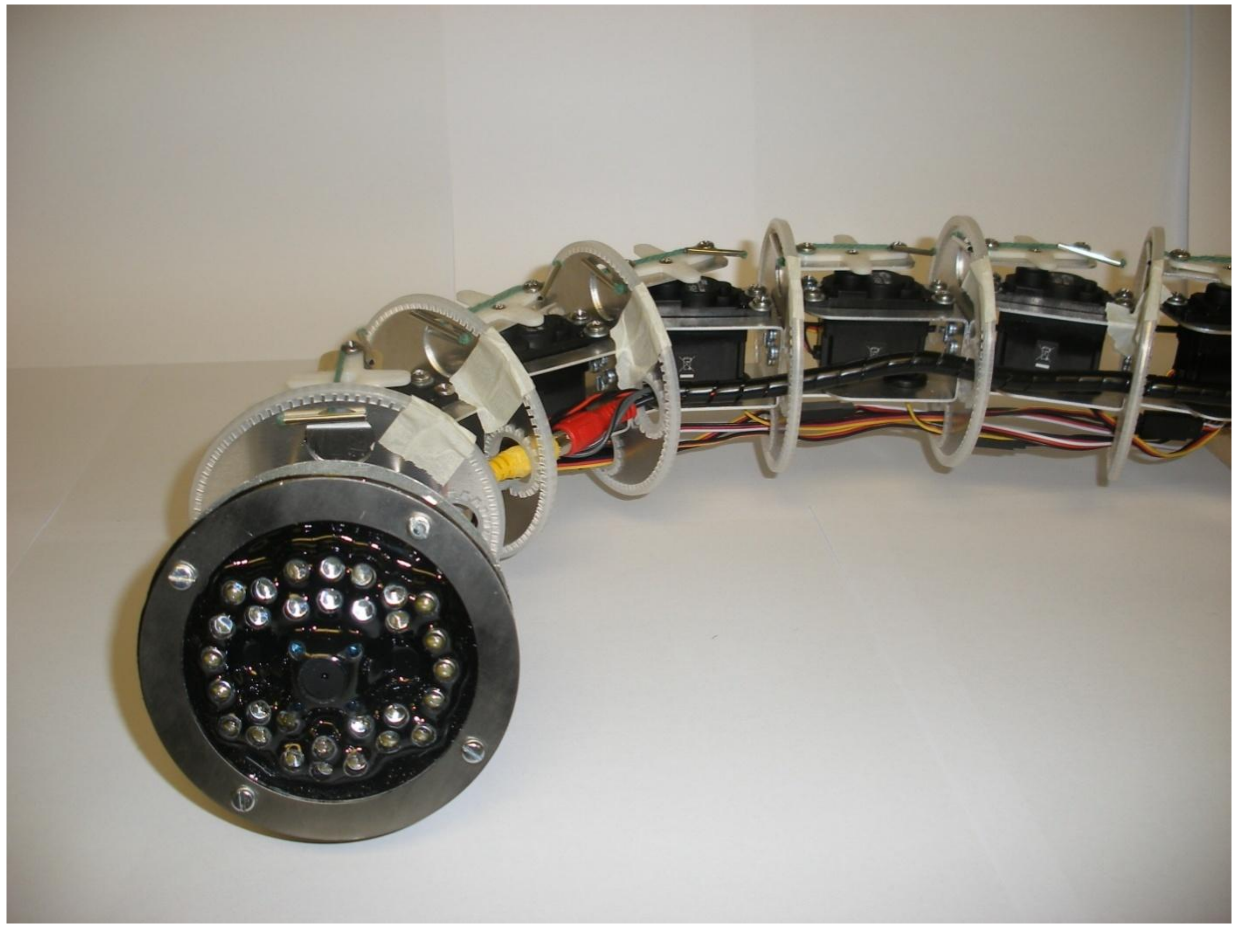
I managed to obtain some free items for my project too. Thanks to Texas Instruments' product sample policy I used 2 DC-DC converters in my project. These were important modules because they produced enough current for the servos to function.

Also the game controller pad was donated to my project by Sam Duke, a fellow DT student.

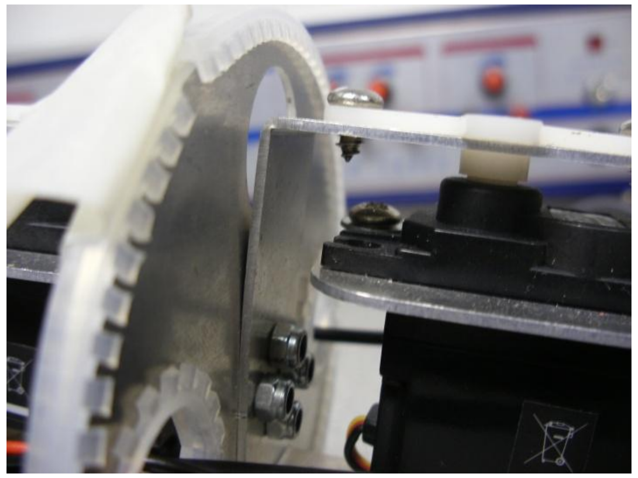
Item	Qty	Total
18pin DIL	2	£0.02
28pin DIL	2	£0.02
8pin DIL	1	£0.02
4MHz resonator	1	£0.18
BC458 Transistors	1	£0.14
Resistors	25	Neg
Diodes	2	£0.06
white LEDs	20	£2.00
IR LEDs	10	£2.25
Servos	7	£20
Xbee module	2	£32.00
Airwave 5.8GHz mod	2	£14.00
PICAXE 18X	1	£3.70
PICAXE 08	1	£1.80
PICAXE 28X1	2	£4.35
LCD Firmware	1	£4.00
Leads and connectors		£15.00
Stereo socket	3	£0.69
LCD monitor	1	£25.00
6x6mm switches	2	£0.24
toggle switches	1	£0.38
LCD screen	1	£24.42
Camera	1	£13.00
3.3v regulator	2	£1.40
Grommets	2	£6.70
Capacitors	10	Neg
Termiinal blocks	10	£0.85
Arial	2	£8.00
TOTAL	£ 180.22	

On the left are the costings of my project. With laser cut parts the total of parts used was £310.
This large number reflects how expensive it is to produce a prototype of anything, however as my project is one of only a handful of snake robots I had to pour significant recourses it, as there was little material for me to use on snake robots.

With industrial manufacture however I feel that the cost of manufacture would come down tremendously. Although my robot is not intended for general consumers, practices such as mass and batch production would reduce costs. The PCB alone could be put onto one board, made 1/10 of the size and at 1/10 of the price that I have produced them at. For the laser parts price will come down with quantity, however my parts currently work out a t around £2 per piece, which is very reasonable.



Future Developments



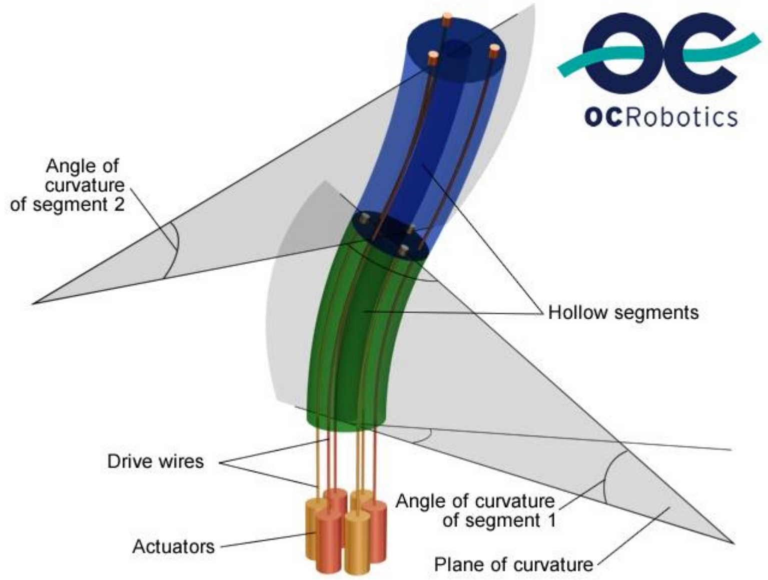
Arm sagging

On this picture it can be seen how the sag is caused in the arm. Due to the simple design of 4 central bolts, the top can flex. This is possibly under-engineered. This can be solved with a new fixing system of 2 bolts at either end of the servo arm.

Servo replacement

If I was to make SnakeBot MK2 I would use stronger servos. I was unable to in the first place due to the cost of these type of servo. The MG995 would be perfect for the job; this is the servo I use to lift the whole arm. If I use these I may be able to mount the servos at 90degrees to each other, this would give the movement in X and Y that users suggested.

The only snake robots that I have seen that have true X and Y movement are the OC robotics modules. However this method of pulling cables from a large control box is far too complicated for my liking. I would be sure that an easier way to move in x and y was possible. I already have some ideas on how to do this.



SnakeBot on wheels

I would like to place the arm on a buggy so that it can be mobile and truly reach its potential as a remote reconnaissance robot. Adding a buggy is almost a project on its own that is why it was attempted in conjunction with the main project.

Left is a picture of a chassis for a koyosho mad force monster RC truck. That is along the lines of what I want the arm to be mounted on. I already have bought the wheels shown in the picture, so the possibility to make the buggy is open.

Evaluation

It has been a good 9 moths since I first began to research ideas for this project. Now I have a finished prototype of the project that is working well.

From the testing I have learned a lot of things, when testing against the specification all the points were satisfied adequately. So I am happy to say I have accomplished what I set out to do, to make a new type of robotic arm that is better and different from the rest.

However as with any prototype it's not the finished product and there are many ways to improve it.

The PICAXE system has somewhat limited me. Because of how it has been made i.e. a regular PIC microcontroller that has had a bootstrap loaded onto it so that's its simplified commands can be used. This is a great system that has allowed me to easily build up the program. But if I just use a blank PIC and then build up my own program I can have much more freedom in my programming. Where this was most disruptive was in the servo control, although the PICAXE can control a number of servos it does not do it very well. I had 8 servos in total, sometimes they would twitch slightly, and this is because the servo pulse is probably not correct. A possible microcontroller to use is the ATmega32, this is a powerful 16 MHz processor, it is capable of handling multiple servos and performs other tasks easily.

Another point on the servos is that they are relatively weak; I have to have the base servo constantly holding at centre to help support the weight of the arm. I would use next time more powerful servos.

Another big thing to come from the testing was the size of the circuitry. If the product was to be produced industrially components need to be changed for smaller size, surface mount IC's would reduce space and a much smaller LCD screen would be needed. The circuit board itself would be double sided; this is easily done in industry

The cost of my project was high, perhaps unavoidable to a degree but it can be reduced significantly. The components are bought in bulk and therefore cheaper, an efficient production line will further reduce costs. Bringing the production costs is important for both producer and consumer, the product needs to be good value for it to be bought, and also a manufacturer wants to have a good profit margin on it.

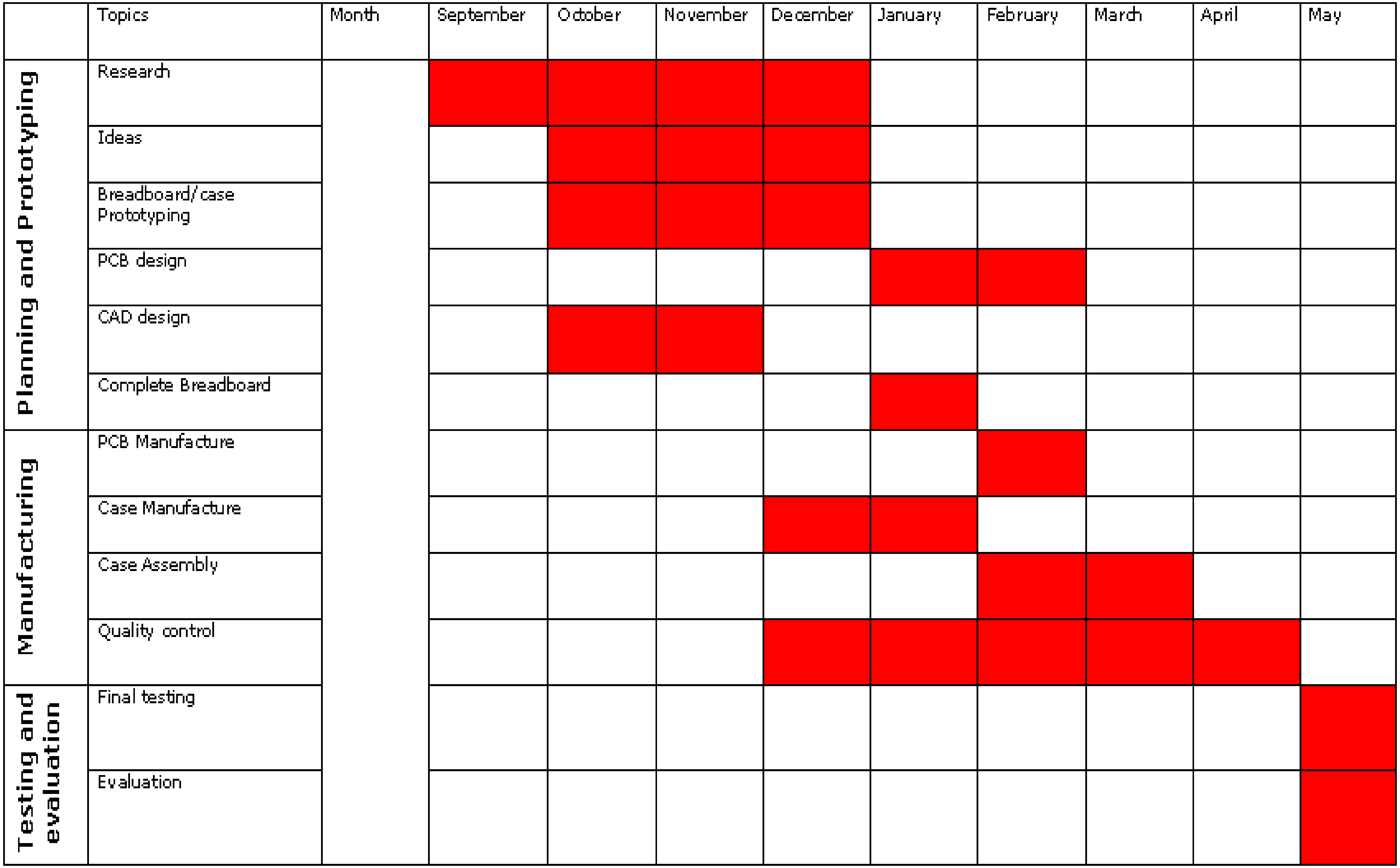
The XBee module which has made this possible is not being used to its full potential, I have only used one feature, and it has many others. The XBee is programmable through a serial interface with the computer, and it also has an address. The address is just like a mobile number, this means that multiple snake robots can be used together as a cluster in the same area. However to do this a serial interface needs to be set up, this is easily done through a computer but for the user to do it on their own to perform tasks such as enable sleep mode and select which address to transmit to without a computer you would need something like a MAX3232 serial IC, this would take some time to get working, but I am confident it could be done as I have been looking into it towards the end of my project.

The AV side of my project gave me a lot of headaches. First there was all the trouble with the interference with the 2.4GHz modules, when we think that that will be solved by the 5.8GHz modules, more work and investigation needed to be done to get them working. When they all did finally work I was somewhat disappointed with their quality, perhaps this reflects their low cost to buy. Ignoring the picture quality they still suffered from interference when moving between the two modules, despite being on the clear 5.8GHz spectrum. I think this was because they are analogue devices, the 5.8GHz band will not be clear for long as the new n spec of Wi-Fi is being introduced which works on 2.4 and 5.8. the solution to this is to use a digital AV sender because the digital units would have in place program procedures to verify that what is being received is intended for it.

Overall I am extremely happy with the project. I took on this project as a step away from the heavy electronics and programming that I had been doing in recent years. I chose a more mechanical project as it was mechanisms and hardware that first interested me in Design and technology, however as it turned out it was an excellent combination of the electronic and mechanical sides.

To be one of a few actively working on snake robots made me feel as if I was truly innovating, and I am proud of the solution I produced. I was also very pleased to have made contact with Stephen Bridges of QinetiQ, a leading defence company, his input helped a lot in the development of the project.

Gant Chart


Topics
Month
September
October
November
December
January
February
March
April
May
Planning and Prototyping
Research
Ideas
Breadboard/case Prototyping
PCB design
CAD design
Complete Breadboard
Manufacturing
PCB Manufacture
Case Manufacture
Case Assembly
Quality control
Testing and evaluation
Final testing
Evaluation

Bibliography

My thanks to all that helped and provided me with information through the duration of my Project.

People/organisations

Individuals (Names not shown on the online version)
Lasershape
Texas Instruments
The Arkwright Trust

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Google.com
Wikepdia.com
Maxstream.net
PICACXE.com
PICAXEforum.co.uk
Rapidonline.com
Maplin.co.uk
Ebay.co.uk
Amazon.co.uk
Ti.com
QinteiQ.com
OCrobotics.com

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Bodyspace: Anthropometry, Ergonomics and the Design of Work (by Stephen Pheasant)

Robot Builders Bonanza: 3rd edition (by Gordon McComb and Myke Predko)

Software

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