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AN INVESTIGATION INTO THE CONSTRUCTION OF AN ANIMATRONIC MODEL

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Abstract; *C Peel: An Investigation into the Construction of an Animatronic Model*

This thesis investigates the development of an animatronic robot with the objective of showing how modern animatronic models created as special effects have roots in models created during the scientific and mechanical revolution of the 17th and 18th centuries. It is noted that animatronic models that are available today have not been described in any great detail and most are covered by industrial secrecy. This project utilises technologies developed during the latter part of the 20th century and into the beginning of the 21st century to create the design of the animatronic robot.

The objective of the project is to bring effective designs for animatronic robots into the public domain. The project will investigate a large variety of different mechanisms and apply them to various functioning parts of the model, with the design and method of each of these functions discussed. From this, one main part of the project, the jaw, will receive the focus of construction. Once the construction is complete this will be evaluated against what improvements and changes could be made for future iterations, with a revised design produced based on what has been learned.

Keywords

Allosaurus

Animatronic

Autonomous

Control System

Dinosaur head

Museum Exhibit

PIC16F84A

Robotics

Special Effects

Visitor Attraction

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Chapter 1

Introduction/History

This chapter describes the background and history of automatons and animatronic robots, describing what was invented, when and by whom. It goes on to describe how this has evolved through the generations of technology and describes some recent models including who created them and how they work. This chapter includes a summary of all the chapters at the end.

The project has the following objectives:

The objective of this project is to create a life-size dinosaur head based on a dinosaur that once existed. Similar projects have been attempted and completed in the past; however the methods used were commercial secrets and have not been published; there is little to go on other than brief descriptions of the models and equivalent images. This project is to investigate the methodology of creating such a model and to place that methodology into the public domain. The head should encompass the main actions that were required by the commissioning body and have been attractive to model creators since the early times. It shall be used for demonstration purposes as an exhibit by the commissioning body, being the Department of Cybernetics. The head should make some actions which should be highly repeatable, and should be constructed from lightweight and inexpensive materials. Therefore a compromise will need to be made to find the optimal balance of the mechanism being fast, light, accurate and strong. The head should be autonomous and be able to run of its own accord, though there should be some element of exterior control. The quality of the aesthetic of the head should be realistic enough to be able to place as a museum exhibit, but does not have to be the extremely high quality of, say, a Jurassic park model. The system of control should be placed within the head. The documentation of the project will be placed into the public domain to form the basis of other projects to come in the future.

History of Animatronics – Introduction

Humans have always been fascinated with extraordinary beings and the ability to make things move and perform. The idea of a robot has been around for a very long time. However the models that have been made have rarely been described in detail either how they were constructed or how they worked. Many models like Von Kempelen's chess playing robot (Sayous 2001) depended on deception for their operation and could not be expected to be described. The older models are only known about from writings by contemporary scholars, or the surviving ones have been photographed yet this is all that is really known about them. More recent models have been made for entertainment purposes by Walt Disney's Imagineering (http://disney.go.com/disneycareers/college/wdi/), Jim Henson's Creature Workshop (www.henson.com), Stan Winston (www.stanwinstonstudio.com) or similar studios, all of whom like to keep their methods to themselves as trade secrets and so do not detail their methods of construction or the mechanisms that they use. The objective of this project is to start the process of placing the construction of animatronic robots on a proper academic basis for discussion and development. There are few basic references, where they are available they have been used but much of the functionality of modern systems is based on the properties of modern materials and control systems which have not been referenced earlier. The project starts with a survey of the field and the referenced works.

Mechanical Automata: Precursor to Animatronics

The very first example within fiction was an ancient Indian myth about mechanical elephants that can move. The ancient Egyptians created statues of their gods that were given movable arms; the priests hid inside them during ceremonies to make them move and pretend that the statues were activated by the gods themselves (Critchlow 1985). The level of understanding of the people at this time meant that even though it is incredibly rudimentary, it most likely fooled all the plebeians into thinking that it was really the gods moving the statues. In Homer's Iliad, written in 800BC, there is a story involving the Talos, a sentinel "programmed" by the gods to defend the isle of Crete. 500 years later, Hero of Alexandria, of the Ancient Greek civilisation, took this another step when he designed hydraulic statues, able to move using elaborate systems involving water weights (Fuller 1991).

There were no documented examples of this kind of model until the 16th century when Hans Bullmann created the first androids. These were simply models that could play musical instruments for the pleasure of paying customers. There were only a couple of other examples from this period of time, with German Johann Müller apparently making an iron fly and an artificial eagle, and Englishman John Dee making a wooden beetle, all of which could fly (Timeline: Real Robots 2001). Then there was very little evidence that more automatons were being created until the 18th century when the Swiss invented the clock and used clockwork to create various automatons. Early medieval clocks were built with life-size figures of man, angel and devil striking a bell with a mace. A man named Jacques de Vaucanson became known as a pioneer for his inventions. Having previously studied anatomy, mechanics, music and physics, he turned his attention to building models which could mimic biological functions. His first creation was the Transverse Flute Player, which was finished in 1737. It could play 12 different tunes, but what amazed people was the fact that the player actually played by 'exhaling' and moving its fingers. It worked using an intricately carved drum, similar to one used in a music box, to control several series of cams to either hold down one of the covers to make the sound, or control the rate of airflow across the flute to control the volume of the sound being made (Sayous 2001). An image of the flute player taken at a recent exhibition is show below in *Fig 1-1* and gives an idea of the level of detail required to construct such a model and make it work. As interest in the player diminished, Vaucanson set to work on his next two machines. The first was another humanoid musician, this time playing a galoubet and a tambourine. Having built a machine that could play one, Vaucanson remarked that the galoubet was the most unrewarding and tiresome instrument to play. The other automaton was a duck that could eat, drink, dabble in water and digest like a real duck. This duck was made so that the insides could be seen by onlookers as the duck digested some grain and then excreted green-looking gruel from its sphincter. By 1741 his name had become so well known that Vaucanson was offered the job of General Inspector to the silk industries. This led him to lose interest in automatons though he built machines and perfected tools for silk manufacturers.

The next famous automaton was built by Friedrich Von Knauss who created a series of writer automatons. The last of these was the most impressive, able to write a long text in multiple languages. It worked using a 3-inch sphere with six opening sections with the mechanism inside (Sayous 2001).

Fig 1-1 – The Flute Player

In 1770, Henri-Louis Jaquet-Droz, his father Pierre, and a couple of their skilled friends created a set of three automatons, which were the most realistic created so far. The first was of a child who was able to write a short text. The second was of another child, this time able to draw four pictures. This automaton had the notable features of co-ordinating the eyes and pencil movement, and being able to blow the pencil dust away. It was well renowned for its realism, which was something to be said for the final automaton. Built primarily by Henri-Louis, the third automaton was a musician playing the piano. This machine was highly detailed and while playing, looked alternately between the fingers on the keys and the music it was playing (Sayous 2001). Based upon the success of the first three automatons, Henri-Louis remade the first two, this time with more limited abilities to draw pictures. Below in *fig 1-2* is a portrait of the head of the musician. This gives an idea of the detail that the model featured.

Another marvel of this period was the bird organ invented in 1770, which used cams, levers and a clockwork mechanism to provide the movement of the bird's wings, head and beak. Valves and pistons were also involved in this model to create a variety of bird whistles. Whilst activated, the bird organ could realistically move its head and wings, and opens and closes its mouth while it whistled a tune. These were mechanical wonders for the period, and the only people who could have them were the elite classes (Critchlow 1985).

Fig 1-2 – The musician built by Jaquet-Droz

The Abbot Mical was the first creator to build a talking machine, in the form of two heads in a little theatre that shared lines of a dialogue. The mechanism used to produce speech was imperfect, but that meant that the voices were not exactly correct which one observer described as 'superhuman' (Sayous 2001).

Musical automatons had become well known and a number of people had started to build their own versions. Pierre Kintzing created a model of a lady playing a dulcimer, a kind of harpsichord, which was only eighteen inches big. This model also has the ability to change the expression on its face to look like it is enjoying playing the instrument (Sayous 2001). This model impressed Marie-Antoinette so much that she bought it with the view of donating it to the Academy of Science.

Joseph-Marie Jacquard was given the task of restoring one of Vaucanson's looms. These looms were based on punch cards and Jacquard took the looms one step further by having the punch cards on a loop, which would repeat a pattern indefinitely (Simkin 2002). Initially, these looms were burned by unhappy workers who thought that they would take over their livelihoods. However, the French government intervened and saved them, and Jacquard had invented the first known re-programmable machine.

The next, and possibly the most complicated automaton came in 1805 with the creation from Maillardet. He created a machine mimicking a man drawing and writing at a desk. He chose not to cover it so that the internal workings could be seen by all. It had an unusually large memory and very precise movements involving an unusually complicated series of cams, levers and shafts. The automaton had several things it could perform, one of which was to draw a fully-detailed fully rigged, threemasted schooner with three decks of ports, which took it about 5 minutes. This model could also write a five line poem in French, which identified it as being Maillardet's; it signed its name when it was found after having been lost for some years – the first instance where a machine identified itself (Critchlow 1985). As a result it is in the Franklin Institute Science Museum, Pennsylvania.

Stévenard had a turn when he invented four different models with different capabilities, all around 1850. These were the Illusionist, the Magician, the Song Lesson, and the Flute Player. These were probably the most wondrous models ever seen, as the models mimicked perfectly the human counterparts of the tricks they represent (Sayous 2001). The Illusionist is situated with a table in front of him, and a smaller table to the side, on which three cups are placed. It performs the trick where balls are hidden and revealed within one of three upturned cups. After that trick is finished the Illusionist presents a single, larger cup out of which a golden egg is produced. This egg splits in two and a bird comes out, falls off the table and twitters its song. It is then scooped back into the egg, which in turn is pulled back under the Illusionist's table. To finish, the character Punch emerges from the same cup to entertain with its frolicking before the Illusionist bows to signal the end of the show. The Magician is situated in a little temple, and the act is to pull an index card from where they are kept. Four swans bring the index card, once it has been chosen, and a pleasant tune begins to play. The magician looks at the one who has just posed the question on the card, consults his book and bashes the doors of the temple with his stick. The doors open to reveal a small block of black enamel. A small imp appears and demonstrates the magician to a vase of golden ink, into which the stick is dipped so that the magician can write the answer on the block. The Song Lesson, which is also known as the "Young Lady and the Blackbird", is a model of a rich oriental lady operating a billy while holding the blackbird. What is remarkable about this model is that the lady is only fifteen centimetres tall, with the blackbird scaled to size. Yet the blackbird, despite being a matter of centimetres big can still open its beak, move its eyes, head and plumage, and whistle a song. Finally, the Flute Player is just over thirty centimetres tall, and can play a multitude of tunes, mostly by Rossini and Bellini. The model plays the flute using real finger movements.

All of these models have the fact about them that they are using scientific principles to convey an artistic notion. The inventors were all breaking new ground in the methods and technologies used in constructing such mechanisms. Contemporarily these were modern day marvels designed to demonstrate these principles to a wider audience and many that have survived the years have ended up as museum exhibits.

20th Century Electromechanical Automata

Despite this flurry of invention, it was not until 1921 that the word "robot" was first used. Karel Capek, a Czechoslovakian playwright, wrote a play entitled "Rossum's Universal Robots" about an inventor and his son who built a number of robots to make human life easier, but these robots rejected the notion of being slaves and turned on humanity. The word "robota" is the Czech word for a worker providing compulsory service (Iovine 2002).

All of these examples have been based on what we would currently call "sequence machines" in that they can only do what they do in a certain order, e.g. Maillardet's automaton would draw the image of the ship the same way every time. However, in the early 1940's the computer was invented. With the development of the computer, many technologies were made faster and easier. In 1956 George Devol created and patented the first programmable robot. This was a playback machine and used a magnetic process recorder to control the actions of the robot (Critchlow 1985). A playback machine is similar to a sequence machine with the minor exception that the actions that were being played back could be altered by changing the magnetic tape. The problem with a sequence machine is that once it is made and programmed, it cannot be reprogrammed. It took a few years, but businesses realised that the robot was the way forward because they can do the jobs that humans find boring and repetitive, or just plain dangerous so the businesses started implementing them in industrial applications.

In 1960, Disney first used the phrase 'Audio-Animatronics' when they opened Nature's Wonderland in May of that year. It is called 'Audio-Animatronics' because it works using sound as cues for the next action from the puppets (Anderson 1996). The technology of the day did not allow for the variety of actions that Disney wanted to use with the models, they had to invent a method that would work. A few years previously, NASA declassified the IRIG (Inertial Reference Integrating Gyro) system. The IRIG system was controlled by a series of tones, with ten different tones available so that the tone reader would not be confused between different tones, and each tone activated something different. Disney saw the potential of such a system in automating models for live performance using one tone to activate one moving part of one model. For the actions that Disney wanted to use, this turned in to an horrendously complicated system. For every action that needed to be executed, right down to the blinking of eyes and waving of fingers, there needed to be a tone. The way they got around this was to duplicate tones for different things at different times. All the actions were rehearsed and timed, and then the tones were recorded accordingly. These were then mixed down onto one tape at a time. Because there were ten available different tones, up to ten different things could be happening at once, so the programmers made sure that there were never more than ten parts moving within the duration of one tape. However, when the tape was changed, the tones were sometimes reassigned to parts that had other tones previously; it was all dependent on how much they could condense the system. These systems became obsolete with the introduction of processors and integrated circuits.

In 1971, Marcian "Ted" Hoff created the first microprocessor for Intel, the 4004 (Maxfield & Brown 1997). This meant that the computers in control of the robots did not have to be so large and so as the computers shrunk, so did the robots. People worked out that robots do not just need to be in factories. Today, there are a large number of robots in factories, but there are also a large number of robots that are not. These robots are based in museums, theme parks, hospitals or space. The hospital robots are a very new breed of robot where the doctor can control the robot's movements. The robot has a mounted camera connected to a monitor above the robot's control panel (Exhibits: The EndoVia Surgical Robot 2003). The robot is actually very small and is designed to carry out keyhole surgery, the operations which only need to take a tiny amount of space to perform. These are generally gastrointestinal, gynaecological or cardiac operations. A positive point about the robot is that because it is translating the movements of the doctor, it is very steady and accurate. Also, because it is a tiny robot performing the procedure, there is less chance of contracting an infection; the healing times are much shorter, as the incisions made to get to the organ are very tiny cuts. Using conventional techniques requires having to open the entire chest to get to the organ.

Defining "Animatronics"

The automatons mentioned above are the precursor to animatronics; small models based on a humanoid or an animal that can move and impress people, demonstrating life. A shortened version of the phrase *animate electronics*, the word Animatronics was coined to describe such robots. Animatronics are also appearing in the entertainment industry, in films and at theme parks. Theme park robots are generally either part of a ride or as a welcome robot to greet guests at the gate. Disney developed Lucky, the audio-animatronic dinosaur (Now Roaming Disney's Animal Kingdom, Lucky the Dinosaur Has Guests in 'Prehysterics' 2004). Standing at 9ft tall, the purpose of the robot is simply to walk around pulling a flower cart and interact with the guests at Disney World. Animatronics are also used in films quite regularly, usually when a realistic looking model is required of something that does not really exist. The most famous example of this is the film series 'Jurassic Park'. The film is about some scientists who genetically recreate dinosaurs on a remote island, though obviously with films of this type, things go wrong and the dinosaurs break loose and wreak havoc. The models of the films were achieved by creating life-size working models of the dinosaurs in question for the filming.

Animatronics are desirable because they can represent anything that can be built into a working model. Museums, particularly science-based ones, use a lot of animatronics to demonstrate principles or methods and teach people how things work, e.g. physics, the human body etc. Until the museum dissolved, there was a large accurate model of a human heart at the California Museum of the Heart (Rubenstein 2001). This model actually beats and has lights to demonstrate the flow of blood around the coronary system, and can even demonstrate a heart attack. Other exhibits at the museum included a giant walk-through heart-valve, as well as another section demonstrating a coronary artery complete with cholesterol plaque as a warning towards cholesterol levels.

The word animatronics as a description is used most often within the entertainment and educational sectors; however the space sector also uses similar technologies and styles. Driven by NASA, though not exclusively, the space sector has great potential for the use of robotics and animatronics. Robots are built that are sent to examine foreign planets and transmit the data collected to satellites in orbit around those planets, which then forward that data back to the ground control on this planet. Robots are built so that they can be sent into orbit and build the satellites, though this is supervised by humans to make sure any errors are overseen. One high-profile example of this is the recent Beagle 2, sent by the British to detect any history of life on Mars (Mars Express and Beagle 2 2003). Its purpose was to roam around on the planet taking readings of various spectra of data and transmit it to the satellite in orbit around Mars. Unfortunately, it was unable to establish contact with the nearby satellites and was lost.

One conceptual design is of an arm with 21 independent joints (Hooper 2003). Such an arm is virtually impossible to create on Earth; because of gravity it would not be able to support its own weight. However, because there is no gravity in space, the arm would be perfectly suited to such conditions, where it would be able to bend around the random detritus and poke through small portholes.

However, animatronic models can be very time consuming to create. They go through a long process of designing and building to get a finished model (Production Notes – Jurassic Park III 2004). The process begins with detailed designs, which go through many rounds as the designs are refined and perfected. These designs will be scale drawings and will be detailed down to the correct colour, even if it is an imaginary beast. These designs are sent over to the modelling section, which will use the designs and build a small scale version of the final piece, known as a maquette. The model is used to ensure that the original designs were precise, and to verify that the finished piece will be accurate. Depending on the size of the final model, maybe more maquettes will be made as they scale up. They lead to the creation of the moulds of the final model. Meanwhile, the mechanics department work on the parts that will make the model move. Every small bit that will move, down to the squinting of the eyes will be assessed and given the appropriate mechanical parts to allow it to move. This part of the process is usually the most time-consuming. When it is complete, the model is sent back to the art section, where they give the model the final touches to make the finished model.

The most famous examples of existing robotic dinosaurs come from the trilogy of “Jurassic Park” films (Tyson 2003). In these films the dinosaurs are created using a combination of computer-generated imagery and the use of constructed models, with the models being made to actual size. This presents a rather large engineering problem of how the models are built and controlled. In anything over a certain mass the models are made to move using either hydraulics or pneumatics, both based around the same principles of pushing and pulling fluid to produce a powerful motion where pneumatics push air through the piston and hydraulics push oil. This is the most efficient way to move robots that are over 0.5 tonnes. The example that was found was the ‘Spinosaurus’, built specifically for Jurassic Park III by Stan Winston Studios. The dinosaur was around 30ft long and about 15ft in height. This dinosaur was chosen because the filmmakers wanted to create something as big and scary as a T-rex, but they wanted to change the main dinosaur away from that because it was well known to the point of becoming a cliché. This had to be a full size recreation of a dinosaur that was only found once, and the skeleton was subsequently bombed during World War II. A machine of such size could only be efficient if hydraulics were employed. The Spinosaurus was controlled using a remote controller, which had a team of 5 puppeteers each controlling a different section, e.g. one person took the eyes/ facial animation, one person took the arms, one person made it walk etc. Even though these projects share many similarities e.g. create a full size replica of a dinosaur and make it move on demand, this is where the parallels between this project and the Spinosaurus end. The Allosaurus was never as big as the Spinosaurus, and also there was a script dictating the movements to be made, as it had to be a part of the story. This project is going to be autonomous, meaning that it will move on its own accord along one of a number of preset paths, dependent on there being a person around to watch it move.

Film vs. Museum Animatronics

The models that are created today for museums have completely different considerations than the ones for the media. Models created for film are generally used only on the one film and thereby giving them a far shorter lifespan and can have a considerable budget. On the other hand museums do not usually have the kind of money that film studios do and their models need to have a lifespan going into years of use. This means that they need to develop new, better and more efficient ways of achieving their ends for comparatively little money so the engineers working on the models need to use new techniques that build on the old methods to achieve better ways of completing the tasks.

The Spinosaurus is not the only example of a robotic dinosaur in the world; it is, however, the only example with any real information available. There is a

Japanese company named Kokoro who create dinosaurs for public display in the confines of a museum (Roaring T-rex robot unveiled 2001). They built a ¾ size Tyrannosaurus Rex to just sit and behave in its pen. The actions it was given include thrashing its tail about before making as if to eat the head of the nearest onlooker. The T-rex roars and the sound reverberates around the whole museum. Its actions are controlled by a large number of pneumatic pistons under the skin. Three pictures, showing the model with its skin, without its skin and detail of the jaw mechanism can be found below in *fig 1-3*. As can be seen from these images the frame was constructed using metal and the mechanism works using a hydraulic actuator. This allows the machine to be strong and accurate, but not fast or light. As a machine, it is much closer to this project than the Spinosaurus. The purpose of this project is to make an autonomous creation, but one that could have user control if needed. All existing examples of animatronic robots have been built under the pretext of commerciality and therefore all information about them has been kept as trade secrets; all information regarding their mechanical, electrical and electronic operations is non-existent, with the exception of the Spinosaurus mentioned above. As a result this project is going to investigate ways of achieving these ends, and particularly the goal of creating a jaw action that can open and snap shut.

In all instances of creating a model of a once living being, be it from the modern age or from centuries ago, the methods of designing the models were essentially the same. The inventor had the grand idea and then had to establish how to put the ideas into physical form. The ancient automatons were all achieved using mechanisms based on clockwork, but this laid the foundation for everything that followed as the old ideas were built upon and led to new ideas. While the ancient models were considered modern day marvels, so should the recent ones, though while the recent ones are more driven by the media and special effects houses they are often still in the pursuit of education but all in the name of entertainment. The techniques developed and mastered back then are still what drives the development of models created for the same types of purpose today. All of the models discussed in this chapter, with a few minor exceptions, have been designed with the concept of bringing an idea to life through mechanical means. They are artistically designed with a realistic aesthetic, and have moving parts to show the actions of the being the model depicts. This is the fundamental factor with animatronics and the main objective for this project – to create a model of a creature that both looks and acts realistically.

Summary

This chapter has discussed the history of animatronic robots from their original conception in ancient myths to modern well known models, describing the various different examples that were built during that time. It has shown that there are a number of favourite actions which will be included in the proposed model. It has discussed in brief terms how modern versions are created from drawing board to finished piece and shown pictures of the finished models. It has also explained that the models created have not generally been described in enough detail on which to use as a basis for models by other people than the original creating studios, due to the fact that the methods used count as trade secrets and so are not divulged to anyone, so this project will have to start fresh to place the information into the public domain, which will be achieved in the following chapters.

Chapter 2 will discuss in depth the development of the main design that will be attempted, including details of all of the individual mechanisms, other methods that could have been used for each of the mechanisms and why each method was chosen. Chapter 3 will discuss the implementation of that design, how the robot was built, all of the problems that arose and how they were overcome, and the compromises that had to be made in the construction of the model. Chapter 4 quotes the original objectives and then discusses how the final construction compares and whether or not each part of the objectives is met. Chapter 5 incorporates the things that were learned in the construction of the model and then describes an updated alternative method of building the model with as much detail for the mechanisms as is found in chapter 2. Chapter 6 will discuss the conclusions reached and the lessons learned from the project as a whole.

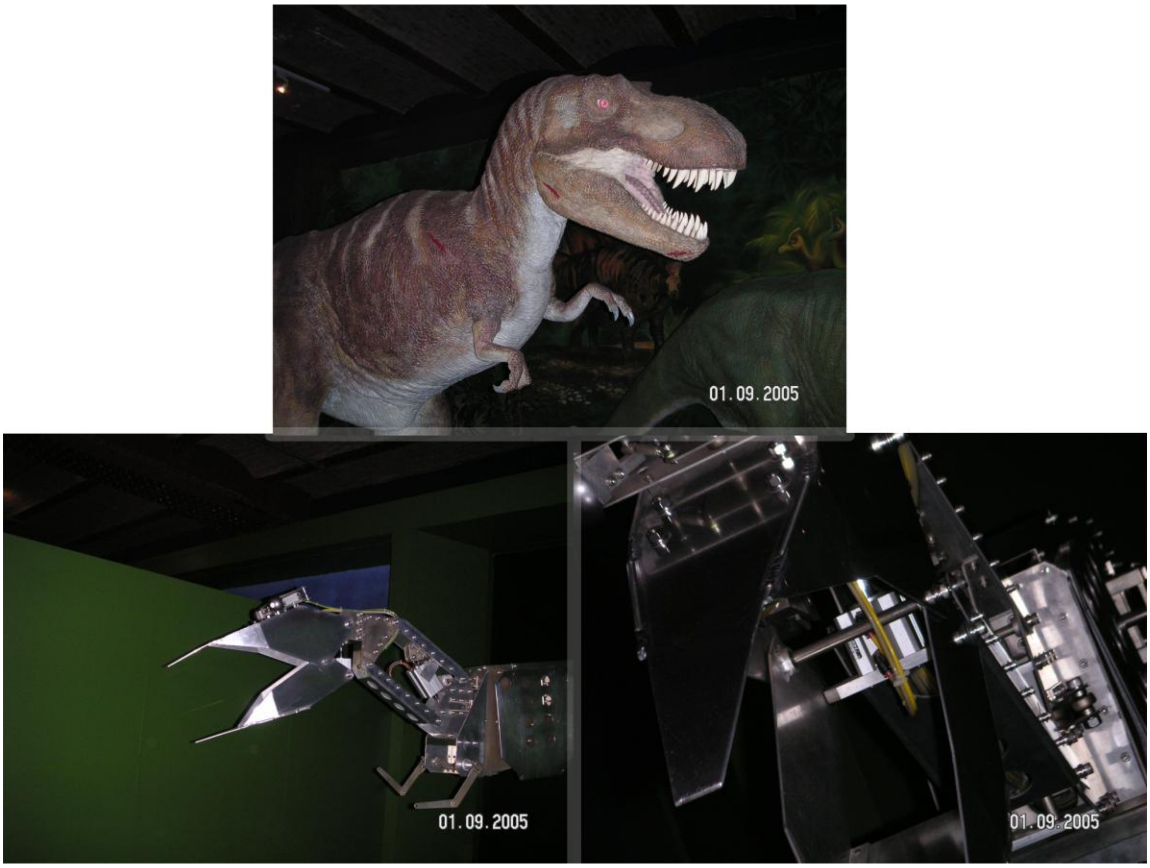

Fig 1-3 – Images of the T-Rex built by Kokoro

Chapter 2

Model Design

This chapter describes the development of the main overall design from generally recognised basics including each individual mechanism that will be tackled, other possible ways of achieving that particular movement and why each method was chosen. In the end a reduced design was used which fully supports the research whilst not having the breadth that was originally envisaged.

In the absence of any previous papers to use as a basis for this project, all that there is to go on are the above pictures and the example they are from being the Kokoro Tyrannosaurus. This dinosaur head will be completed to be used as a basis for future projects.

The dinosaur head chosen to build was an Allosaurus, a bipedal dinosaur from the Jurassic period, whose remains were found in the deserts of Utah. This dinosaur was chosen because the layout of its facial features allows a lot of space for movable parts. The head's largest dimensions are approximately 850 x 310 x 465mm though it forms a tapered shape towards the front of the jaw (Dino Fact File: Allosaurus 1999). This means that a life-size head can be created that will big enough to be a decent magnitude and embed the control systems and actuators, but also small enough to be able to comfortably actuate the moving parts. Images of Allosaurus skulls can be found in *fig 2-1* below.

Design Constraints

There are a number of different methods and materials that the head could be made using, including latex, fibreglass, and papier-mâché (James 1989). There are also a number of different considerations to take into account when choosing the correct material to use to create the model, including cost, weight and strength, aesthetic quality, and ease of use. Overall the model will need to be light, in order for the parts to move, yet strong as to not fall apart. These form two of the main compromises to be made overall in this project. Another consideration is that the model will be left in one place as a display model, and it may not be possible to keep the designer around to maintain it should something go wrong (Heiligmann & Poor 2003). Therefore the model needs to have a repeatable quality to it where it should not fail for a number of years. This in itself provides a lot of challenges.

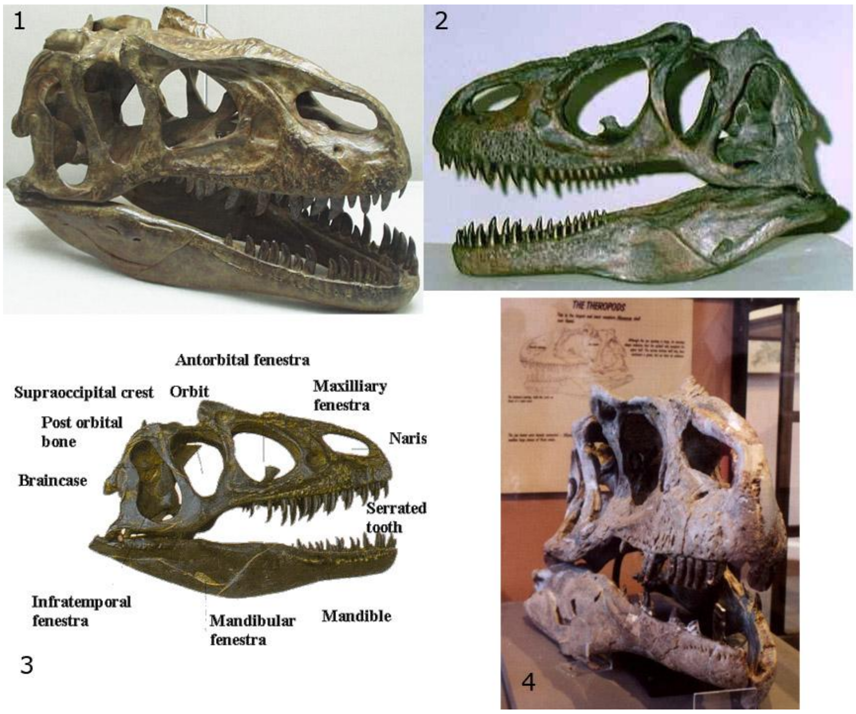

Fig 2-1 – Images of Allosaurus skulls. Sources:
1: http://www.tsm.toyama.toyama.jp/curators/tanaka/image/lobby-apr00/allosaurus.gif
2: http://www.fossilsasart.com/images/dino_skull_allo_juv2.jpg
3: http://library.thinkquest.org/26615/allosaurus.htm
4: http://hex.oucs.ox.ac.uk/~rejs/holidays/rockies2002/ne-utah.html

Material Selection

The strength of a material is usually directly proportional to its weight however if the material is not strong enough then it will destroy itself under its own force and if it is heavy then it will be more difficult to be made to move. Another issue with the weight is with regard to the armature and how it is mounted for general view. If the head as an overall piece is too heavy then it will not be feasible to mount as it would be top heavy and continually fall over. One possible solution to this would be to mount it on a trophy plaque as if a big game hunter had shot and mounted it. However the points of contact would need to be quite strong if it were to remain mounted. Therefore the material used cannot be too heavy. Latex was initially chosen as the base material for this project as it can provide a lot of strength for its weight, as well as the fact that it can provide the most pleasing aesthetic quality. However, it can be quite costly and it can be very difficult to use. James (1989) explains the full process of making a mould and cast using latex, papier-mâché and fibreglass in addition to other materials. Creating a model with full- or semi-rigid latex involves making a basic model, usually out of clay. A cast is made from this model using plaster-of-paris, which forms the basic mould. This is then filled with the latex being used and left to set. A good point with this method is that many models can be made using the same cast. With flexible latex the mixture is made and then a coat applied to the exterior of the model and left to dry. The major downside is that strong latex can be very costly. It is possible that the clay model could be used as the base for the model in question, though in one such as this, where there will be moving parts, then that poses a risk. As the clay dries it becomes more brittle and with the moving parts and mechanisms shaking the model around, the clay could fracture and break. This is why a cast is taken and filled with latex. The rubber aspects of the latex, even fully rigid setting absorb the vigorous movements and hold together much better than a simple clay model. This is the reason that latex was chosen over the other possible materials. To make this project out of wood would require either a very large block of wood from which to carve the shape of the skull and then hollow it out, or procure a collection of thick dowels to attach to one another to provide the basic shape. Neither of these are particularly desirable as the major block would be incredibly heavy and almost impossible to hollow out, and the dowel option would not only be very difficult but it would also fail to provide enough strength. Also it is not possible for either of these methods to reach the required standard of aesthetic quality. Fibreglass is a slightly better option. This can be done in one of two ways, one is to create a mould as per the method used if using latex, and the other method would be to make a model and cover it with the material. If a mould were to be made then a special layer of paint needs to be applied to ensure that the cast is released easily from the mould. The mould is split in the usual way and the paint applied. The interior is then covered with strips of fibreglass cloth and coated with the resin hardener. The model, which can be carved from a block of polystyrene, is then covered with the fibreglass cloth and covered hardener. The difficult part with this is carving the polystyrene to begin with, which is done using a hot wire and then smoothed down using sandpaper. The person carrying out this technique must be very careful as one tiny slip can lead to a lot of extra work to fix the mistake. However once it is completed the model is covered with the fibreglass, which can be much more forgiving. This researcher has experience with the hot wire part of this technique as it was used in creating his Shark Final Year Project at Undergraduate level. The Shark project was designed to only have one movement, which was the swaying of its tail. Once the overall shark had been carved from polystyrene and sanded down its tail was split into four sections, also using the hot wire, to allow for the movement. Raise the Roof, the studio overseeing the project and who have a lot of experience in making static models said that a project of such magnitude did not require a fibreglass shell and that it simply required covering in muslin and painted to give enough of an effect. Fibreglass is most suitable to models that are large or need solid support, of which the shark was neither, as it provides strength and is light. The papier-mâché method is the last to be considered. This involves creating a frame, usually out of chicken wire moulded into shape, and covered with papier-mâché. This does allow for a good quality aesthetic, is very cheap and does not weigh too much, however it does not provide a lot of structural strength on its own. It can be reinforced using wood or metal but that adds weight and cost. However for a low-budget model, a lot can be achieved using this method.

Having taken all of this into consideration, the skull will be constructed from full-rigid setting latex due to the strength it provides, while the outer skin will be constructed from fully-flexible latex, this will be quite realistic for skin but if it is overstretched it may tear so only the right amount should be used. Some internal body parts like the tongue will be constructed from semi-rigid setting latex to give it a solid yet floppy effect. The parts that will be made to move shall be the eyes, eyebrows, eyelids, cheeks, jaw, tongue and nostrils. Each part will have its own controller to carry out each of the head's moving parts. Given that each part will have no more than around 5 different forms of movement at most, and each controller can be given its own unique code then it will be possible to use another controller to oversee the working of the head as a whole using an internal network.

Actuation – Electro vs. Fluid Power

Nachtwey (no date) explains that there are two main types of transferring power from the source to the actuator, namely fluid power, e.g.

hydraulics/pneumatics, and electromechanical power, e.g. motors/servos. The fluid approach is usually the most efficient, from both cost and mechanical views. Fluid power has the advantage that where motors need to be sized to handle the maximum load that it will have to carry, fluid only needs to be sized for the average load. If the application does not require constant motion then the accumulator within the fluid system stores potential energy while the system is static. The fluid pump, which controls the flow to the accumulator, does not have to be positioned in the immediate vicinity of the actuator. It can be in a remote position so that the noise and weight are not necessarily a part of the overall machine. The accumulator must be in a close position to the actuators because this is the source of the bulk of the power that the actuators exert. This also has the effect of being able to keep constant pressure without having to increase the amount of force applied to the accumulator. Also, many actuators can be supplied force from a single pump. This means that if a robot has many different moving parts then it only needs the single input source to supply power to the entire robot.

It is for these reasons that fluid power is used in large robotic applications as well as some smaller applications such as the Kokoro model mentioned above. However, fluid power is very difficult to design and implement if a user has no prior experience or knowledge of using it before. Also, fluid power allows no factors of portability, and generally robots that use fluid power cannot be moved. Only if the whole of the fluid system is incorporated as a whole into the robot can it move. Finally fluid power is not very fast in its movement without a huge amount of pressure behind it, and then it would not be very accurate. In this application it would mean that the robot would be of such a large size as to render it impractical to both the creators of the robot, and the Department of Cybernetics who would be demonstrating the robot. This project is to build an Allosaurus head that is effectively self-contained. This is why fluid was used in all of the dinosaurs built for the Jurassic Park series, where there can be a team of puppeteers behind the scenes controlling the machine, and also why it is not being used in this Allosaurus project. This means that a mixture of motors and servos will be used in this project. Motors work by converting electrical energy into mechanical energy and come in two forms: ac and dc. AC motors are good because they can be powered directly from the mains power supply; however dc motors are preferred as they can be controlled from smaller power sources and it is easier to govern their motion using a microcontroller (Wise 2000).

Servomotors are based on the design of small dc motors but are slightly more advanced in that they have positional feedback control allowing them precision movement. However this positional control means that they cannot turn a full revolution and they usually have a turning circle of around 200° (Iovine 2002). A mixture of small dc motors and servos will suffice in pretty much any combination to achieve almost all application required in this project.

Modular Design Approach

The head will be built using a modular approach. This means that one movable part will be constructed and made to work, for example the tongue, and when that part is working properly shall the next part be constructed and the smaller parts be attached together if necessary, for example attaching the tongue to the jaw and making the jaw mechanism. When all the parts have been built and working properly shall construction on the skull begin. All the mechanisms will be attached together before being placed into the skull. It will be done this way because it will be difficult to fit parts into a preformed skull-piece. It is felt that it would be far easier to make all the parts and fit them together, and then be able to build a skull around that. There is the possibility that when the skull is made it would be too small to fit all the parts inside. It will be much easier to make a skull to fit around the parts than vice versa. Therefore the parts will be built first, starting with the parts that are to be placed in the centre and working outwards.

Tongue

The tongue will be built from semi-rigid forming latex to make sure that it has a 'floppy' feel to it to add some realism. A tongue shape will be carved from clay, from which a mould can be taken. This mould will be filled with latex and left to set. Colours and dyes will be added at this point to give the tongue the relevant colour and then left to set for the relevant amount of time. When the mould is filled, a hole will be left so that the tongue can be attached to the mechanism which will make it move.

The tongue mechanism will be based on the Rack-and-Pinion mechanism, with the rack attached to the tongue itself and a cog on a servo to push it out and pull it back in again (Ives 2000a). The implementation of servos is desirable in these types of applications because they are small and lightweight but can generate a significant amount of torque to actuate many kinds of mechanisms. A servo is controlled by sending a signal to one of its pins. The length of the signal is timed internally and the longer the pulse, the greater the angle of rotation of the arm of the servo. When the pulse ends the servo retains its position but when the servo begins to receive another pulse, it resets and rotates again proportionally to the length of the pulse. This can be built into the functionality of the device into which the servo is being placed in that the zero-point of the mechanism can be set to the full rotation of the servo. When the pulse is sent, it would rotate the arm back to the servo's zero-position before rotating again to the resting position of the mechanism. This would mean that the programming of the servo would require a full-length pulse to initialise the mechanism, but the same pulse is all that would be required to activate the mechanism again. A servo can only usually rotate up to around 200˚, but this is useful for the tongue mechanism as it will be built to work using one big gear that can project the tongue out of the mouth. The mathematics used to work out the size of the gear can be found in *Appendix A*, and is based on the equations for calculating the circumference of a circle. Using this equation, and assuming the length of the tongue to be around 400mm, the gear will need to be roughly 229.2mm in diameter.

The tongue mechanism, e.g. the servo and the rack-and-pinion will be built into a frame that will limit the movement of the tongue to make sure it will not fall out or get drawn back in too far. The frame will limit the movement by making it so that the rack will have pins to run down a designated line within the frame, and the ends will be what stops the movement. This frame will be set into the moulded jaw-piece. The moulding will be based on the same technique as the tongue, as that will most likely be the main technique to achieve all the mouldings. We will have a scale model of an Allosaurus head as a basis for the design and shape. This mechanism could also have been achieved using a linear solenoid. A solenoid consists of a cylinder wrapped with a metal coil, and inside the cylinder is a metal rod. A charge is applied to the coil generating a magnetic flux, which has the power to move the central rod. Solenoids contain a high level of efficiency, however it was not chosen for two factors, both of which are to do with size. The solenoid would need to be twice as long as the length that is to be moved to house the rod in its ready-state and to push it the distance, the other factor is that such a solenoid would weigh too much to be comfortably moved by the jaw mechanism. With the rack-and-pinion mechanism the weight would not be too much as all there would be is the rack itself, some limiting rails that the tongue would travel down and a small motor doing all of the work.

Jaw

The jaw will be made from the main moulded jaw-piece attached to a shaft. The shaft goes through a pivot point and on the other side of the pivot point is an arc of a circle, connected to the shaft with beams to form a Y-shape. The inside of this arc is jagged with gear teeth, to allow a highly geared motor to move it. The added advantage of a highly geared motor is that it can give extra torque power to the jaw and act as a lock if the jaw needs to remain open for any length of time. The toothed arc will have markings on it, similar to a binary optical encoder. There will be a light sensor able to read these markings and feed the information back to the electronic circuit so the machine knows what position the jaw is in. The main jaw motor will need to be reversible but reversible motors are commercially available so it is merely a case of purchasing one – no extra electronics will be needed. This could also have been achieved using a large servomotor. A large servo would give a decent level precision, however the size of a servo that would be capable of moving the required weight overall inside the jaw would be too big for this project, and also the precision aspect would not be as good as binary optical encoder attached to the geared motor. The one aspect where a servo would be better is that it would move the jaw faster but that is part of the balance that needs to be struck in the process of creating such models. The electronic circuit governing the angle of the jaw will also govern how far out the tongue will be at any given moment. A diagram of the workings of both the tongue and jaw mechanisms can be found in *fig 2-2* below.

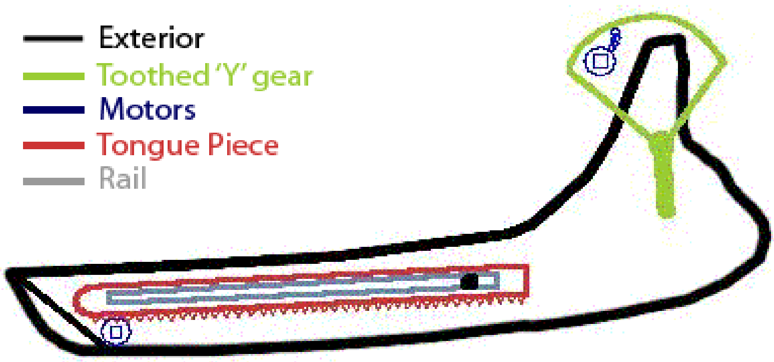

Fig 2-2 – The main jaw and tongue mechanisms

Cheeks

The movement of the cheeks will be controlled using four servos – two on each side of the face. On each side of the face there will be one servo in the middle and one servo at the end. The four points of contact will allow the head to make snarl-like actions as well as smile. This will quite simply be a case where the servos are attached directly to the outer skin of the head. The servos will be attached using arms connected to the actuator of the servo, and to the latex of the outer skin, with the servo arms pointing down in its base position. When the servos are made to move, the arms will rise and stretch the latex and give the impression of a smile or a snarl. This could also have been achieved using linear solenoids also pushing the pin in the relevant direction. However they were not chosen due to the fact that they would have been slightly more difficult to use and gain three states of rest, snarl and smile from them. A diagram of the workings of the cheek mechanism can be found in *fig 2-3* below.

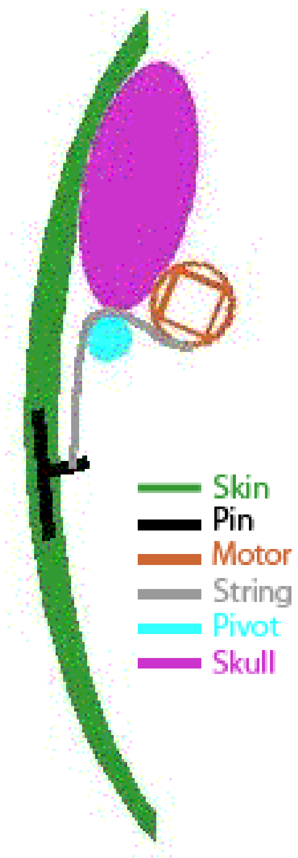

Fig 2-3 – The cheek mechanism

Eyebrows

The eyebrows are going to be controlled in a similar fashion to the cheeks in that there will be a set of servos connected directly to the outer skin of latex with the base position of the servos pointing down and when the servos move they stretch the latex up to raise either one eyebrow at a time or both eyebrows together. There will be two servos to each eyebrow to allow both the inside and the outside of each eyebrow to move independently to give a range of facial impressions. For example, both of the outside servos could rise while leaving the inside servos down to give the impression of anger. Alternatively, both servos could rise on one side alone to give the impression of raising just one eyebrow.

Eyelids

The eyelids will be controlled using a single servo and a gear mechanism to activate both eyelids at the same time. This means that both eyelids will do the same thing at the same time so the head will not be able to wink on one side. If the eyelids were independent then it is entirely possible that a matching blink would be difficult to achieve and maintain and it is felt that a wink is not essential to the project. The eyelids will be made from a harder plastic instead of the latex we will be using for the rest of the head, e.g. ping pong balls would suffice. Each individual eyelid will be cut into two to allow the eyelid to close from both above and below and have the parts meet in the middle for a more natural looking blink. The two parts of each eyelid will need a pivot point and these will have small gears attached to each other. The servo will be attached to a bigger gear that can reach both eyes and will push a gear on each eyelid, which will push the other gear on each eyelid to close them. The servo will be arranged such that the base position will have the eyelids closed and the long pulse sent on start-up to open them. The nature of servos means that every time a new pulse is sent, it counts round from its base position. This means that the eyelids would close and open on one long pulse from the controller, as opposed to sending one pulse to close them and another pulse to open them again. If the eyelids are required to be closed for a longer period then the controller would send a short pulse and then a long pulse after the relevant amount of time.

Eyes

The eyes themselves are going to work in a similar vein to the eyelids in that they will both be connected to the same actuator to make sure that both eyes do the same thing at the same time. However the actuator in this instance will have to be a small reversible motor. There will only be one motor that will make the head look left and right. The eyes can be purchased ready-made and will look like cats' eyes, in that they will be cornered ovals, stretched over the vertical axis. This design means that any movement over the vertical axis would not really be noticed. Also, putting in an extra motor and the workings that would have to go with it would be too much in too small a physical space and so introduces the risk that the workings may interfere with each other. Therefore the eyes will only move along one axis. The eyes will be made to move using a beam connected to the back of each eye, and in the middle will be an arm attached to the motor. The motor will have a binary optical encoder and the small light sensors that can read them to constantly feed back the positions of the eyes to the controller. This controller will have pulse-width modulation capabilities to allow the eyes to move at varying speeds.

The eyes, eyelids and eyebrows all come into Gareth's remit for the project so will not be discussed in any greater detail in this report.

Nostrils

The nostrils will be controlled using a servo, with the arm based along the vertical axis. The arm is connected to a shaft with a wide pin at the other end. Situated just above the pin is a pivot point for two small curved beams. As the servo is activated, it pulls the shaft up, in turn pulling the pin up. The pin gets between the two curved beams, widening them and giving the impression of flared nostrils. The base position of the servo is up, and there would be a long pulse at start-up to relax the nostrils, in a similar vein to the eyelids. This would mean that a single long pulse would flare the nostrils and relax them again in one motion. This could also have been achieved using a small pneumatic pump. This would have worked by blowing a blast of high pressure air down the length of the nostrils. The nostrils themselves would be made with a flap of material behind which the air would blow pushing the material out. This would also give the effect of exhaling. However the noise as the pump blows the air would not sound like a realistic nasal exhalation. A diagram of the workings of the nostril mechanism can be found in *fig 2-4* below.

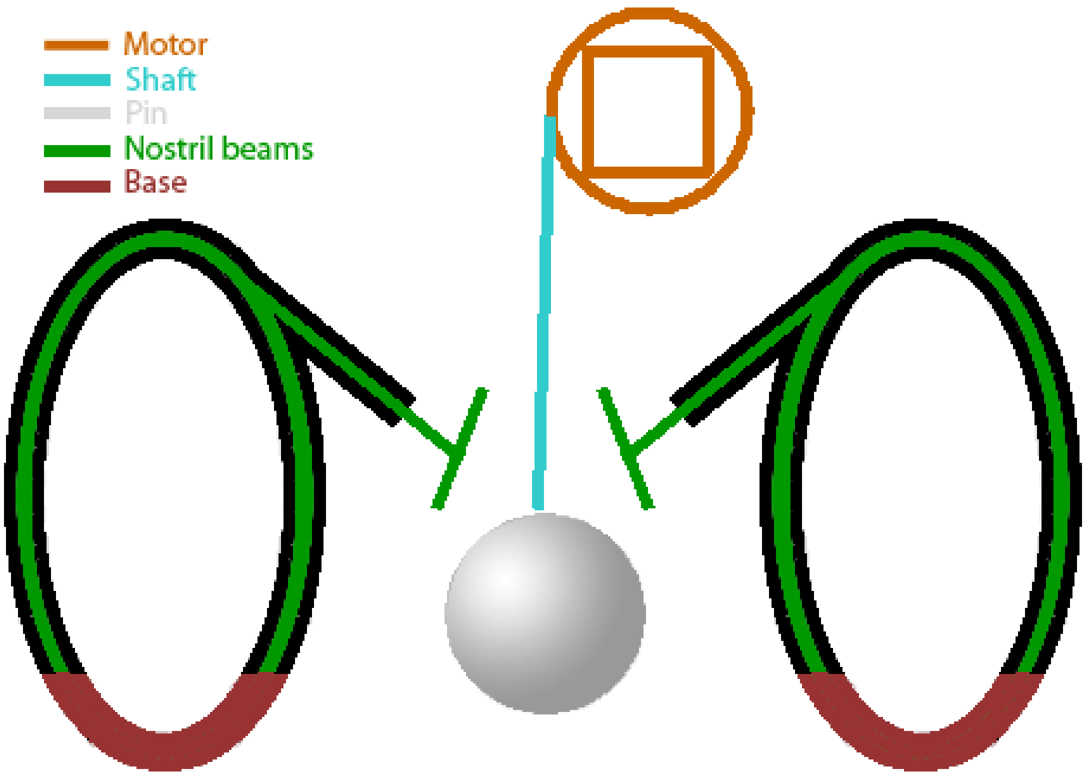

Fig 2-4 – The nostril mechanism

Internal Controller

The controller is going to be designed specifically for the head. It is going to be based on a hierarchical structure, incorporating a system similar to Controller Area Network (CAN) protocols (Nilsson 1997). There will be the main interface with the outside world at the top, which will have a set of proximity sensors connected so the machine is able to detect anyone who is standing close to the head. The proximity sensors will be angled in different directions to be able to see all around the head. They will feed back to the controller and the closest reading will be used as a basis for a random variable and the main factor in deciding the head's action. This means that the closer someone is to the head, the more frequent and the more varied the head's actions will be. There will also be a button panel connected to the controller so that users can see the all of the different behaviours that the head can perform. The button panel will also have the main on/off switch and a button to return the behavioural decisions back to the proximity sensor based variable. There will be a button for each different action that the head will be able to perform. An example of the different actions that the head can perform will be to roar, yawn, snarl, and look around. The roar will entail the mouth opening, the eyebrow outsides rising and a sound effect playing. The yawn will entail the mouth opening and the tongue hanging out, the eyebrows rising, and the eyes closing. The snarl will entail one of the cheeks rising, the eyelids half closing and a sound effect playing. The head will look around simply by moving the eyes left to right or vice versa, going on the readings of the proximity sensors. As there are controllers for each part of the head, each one of these can be given a unique code which the main controller can use to identify the separate sections. As there will be a limited number of actions, it will be possible to have all of the part controllers along the same bus with a control pin and have all of the separate controllers react to the same action signal. All of the separate controllers will be set to run along a preset path for every different action and then return to a resting position. This can be achieved using as little as 4 pins, provided that there are fewer than 7 main actions. It is also planned that there are controls to activate all of the different parts and motions separately. It is feasible to create this alongside the main action bus, as all of the separate sections will have their own joysticks/push buttons to control the different parts, which will individually only require no more than about 4 pins for the most complex actions. Add this to the 4 or so pins required to activate the actuators that move the part in question and it seems that a medium-complex part only requires 12 pins within the controller. A relatively basic microcontroller chip that could be used is the Microchip PIC16F84/A, which has 18 pins of which 13 can be used for I/O purposes. These can be programmed using a specific version of the C programming language designed for the PIC family of chips. The 16F84/A is one of a large variety of chips, all with slightly different functions and capabilities that can make the PIC family useful to this project (Iovine 2002). On the home website of the PIC chips, www.microchip.com, there is a parametric search so one can input the essential qualities that each chip requires and the site responds with the chips that could be useful to each section.

Assembly

When all the parts and controllers have been built and connected and it all works, it will have to be assembled into one final piece. This will be done by attaching all the internal pieces together. A skull piece will be created by carving and shaping a clay version and using that as a basis for a mould. This mould will be filled with latex and left to set. The main skull piece will be cut into two and reassembled with all the parts inside. Then the skin will be applied by coating the head with large rectangular sections of flexible latex and gluing them together to form a tight skin that the parts can stretch to give the realistic impression. Then the head will be set into a large plaque that can be placed upon the wall with a button panel and the proximity sensors underneath. The head will be powered using a transformer mains adaptor to change the voltage down to the relevant voltage for all the motors, servos and microchips.

Design Brief

However all of this in one model would require quite an amount of time in which to properly design and build it and quite a sturdy base on which to mount it. It is of a far greater scale than we should be designing and therefore it shall be stripped down into a workable design. There will now only be two moving parts, the eyes and the jaw, of which this project will focus on only the latter. However it is possible that the aforementioned design can be used as a basis for a grand scheme whereby as new students come on to this particular project they can choose one of the modules to build and add to the model each year. It is also reminded of the original objectives and how a large part of the project is to look at the compromises that have to be made over the accuracy, speed, weight and strength. The new design of the project is of the jaw of a head that can open and snap shut. The mechanism will open the jaw at a suitable pace as far as is necessary and should then snap shut. The jaw should not weigh too much or the mechanism will not work properly. The enforced snap close of the jaw will present a force that would have to be absorbed without shaking the model apart. This is where the main compromise comes in to effect.

Design Issues

The mouth is an essential part of an accurate head and usually does something in every example. However, the mouth is such an under-evaluated part of a robot that information on previous examples is quite difficult to come by, particularly in dinosaur-based robots. Comparisons could be made with humanoid robots but the problem is with size. A study at the Department of Cognitive Science, at UC San Diego, built an anthropomorphic robot where all movements are made using simple off-the-shelf servos (Triesch [no date]). This is appropriate given that the size of the robot is that of a normal human and therefore the servos do not need to be particularly heavy duty. This project of the Allosaurus is also going for scale, but it is also going for an accurate depiction of the Allosaurus and the mouth needs to snap shut. Here lies the other problem. The snap is what makes this project unique and there are no previous examples of anyone constructing such a model. The main compromise of speed, accuracy, weight, and strength has always been considered in other projects but with a different outcome. The Kokoro models mentioned at the end of the first chapter decided that the strength should come from a metal frame and the accuracy from pneumatic actuators; however this comes completely at the expense of the aspect of speed. The examples previous to that were the ancient automatons from the scientific revolution of 1600-1900. These models still had to come in with the same considerations, though the models they were creating were all about authenticity. These models lived up to all they were aiming for but when it comes to the compromise, they were as fast as they needed to be and highly accurate, however it is thought these models did not require much strength and support. All of these automatons were activated using clockwork or similar mechanisms, the forces involved were negligible at most so they were easy to keep entirely self-contained.

Jaw Actuation & Motor Positioning

This project requires the jaw to snap closed meaning that the head will need to generate enough force not only to open but to keep it open and close it again with the release of the force. As to how this can be achieved, simple servos are not going to be enough. Also, this researcher feels that for the actions the head needs to complete it would make more sense to use motors than pneumatics or hydraulics. The reason it makes more sense to use a normal motor as opposed to a servomotor is because a servomotor has to turn back to its basic position every time it is told to move. This does not leave much leeway to snap shut. The snap would have to come from an extra force making it slam back shut. This could either be a counterweight or a spring. The motor that is to actuate the jaw could be set into the lower part of the head, being the actual jaw. This may give enough force to slam the jaw shut. However a better way to close the jaw would be to employ a torsion spring around the main pivot. If a microswitch were positioned such that it could be closed by the spring then it could be used to cut the power to the motor. This would leave the tightened spring with nothing to hold it so it would slam back into resting position, completing the task of slamming the jaw shut. One way of achieving this would be to use a string attached to the rear of the head with a spring to close. The jaw could be modelled in the usual way of making a clay piece and covering it in latex to make a mould. The mould will then be filled with a hard-setting resin that will become the main jaw piece. This jaw piece will overlap the main (top) skull piece to allow a pivot beam to go through the middle. The pivot beam will be attached to the top piece using support beams and the jaw piece will be attached with a tube that the support beam will go through. This will allow the pivot beam to stay rigid while leaving a lot of space to allow the jaw to move. The pivot beam will carry a torsion spring, set beside the inside wall of the beam. One end of the torsion spring will be attached to the top piece, while the other is attached to the jaw piece. There will be a motor set in the top piece that will actuate the jaw's movements. It will do this using a string anchored to the back of the jaw piece behind the pivot beam. The further toward the rear the attachment the more effective the action will be. Therefore the anchor will be as close to the rear as will allow a straight line. This means that the motor will activate, the line will become taut and pull the jaw open. There will be a limit switch set at the point the jaw is most open. It will be set onto the pivot beam and will be hit by the jaw end of the torsion spring. The purpose of this switch will be to deactivate the motor. This will mean that when the jaw is activated then the jaw will open until it is open enough to hit the switch. Then the only force acting upon the jaw will be that of the spring and the jaw will slam shut. The force of the snap will be quite strong and will need absorbing. This will be achieved by lining both sides of the angle with blocks of wood. This has the added advantage of giving a suitable sound effect when the jaw snaps shut. However the wood will remain hidden behind the corners of the mouth. The teeth will be made of latex and will have holes in the gums for the teeth to fall into to protect them from the stress of the jaw slamming shut. The issues with this mechanism are that the forces that the motor would be required to overcome include the spring as well as the weight. To achieve a reasonable slam then the spring would have to be strong which would limit the speed at which the jaw could open. Therefore, while this mechanism is workable, a better mechanism could be achieved.

Another way the jaw mechanism could be achieved would be to set the motor into the rear of the jaw to act as its own load. The motor would pull on a string attached to the roof of the skull and when it had opened far enough it would hit a limit switch, which would cut the power to the motor. With the motor as its own load, the weight would slam the jaw shut. It was noted that there should be a weight limit to the jaw to ensure that the jaw moved at all as well as the weight considerations of the head as a whole. The jaw weight limit was set by the supervisor at 5kg. This meant that the sum of the weight of the jaw piece as a whole as well as the motor and any moving parts had to be less than 5kg. The kind of motor required to move that amount of force could weigh a bit in itself so that meant that this could not be guaranteed. As such it was redesigned. The final method for the jaw mechanism to be considered would be to use an eccentric cam with a pair of arms to pull the rear of the jaw up (Wise 2000). The motor will be set into the top part of the skull and will drive the eccentric cam. The rear of the jaw will be attached to two legs which meet at a pin, which will be raised by the cam. The pin will also be attached to a spring, the other end of which is connected to the bottom of the top part of the skull. This will allow the jaw to slam shut. The sections that should be noted would be that the arms would contribute to the weight considerations and that the force of the spring would run counter to that of the motor. Therefore the motor that would be required would need to be a highly specialised one to achieve the correct speed and generate enough force to move the jaw as a whole. Also the eccentric cam will allow for a lot of force to run over it, similar to a worm gear. However a mechanism this simple can be controlled using hardwired electronics. The motor will be connected to a 555-timer which will make sure that the cam will only turn one revolution. The 555 can be triggered either by a physical switch on a button panel, or it could be triggered by a pulse from an overall controller.

Point of Rotation

Our main pivot point will be constructed with a bearing on each side connected by a beam through the middle. This beam will be crucial to make sure that the bearings are lined up on each side, and also to bear the jaw as a whole so that it might be detached. If the bearings were inserted in their designated position and attached then the top part of the head would be permanently attached to the bottom meaning that if any problems were to arise, it would be most difficult to address them.

The jaw will be placed and secured onto the beam in a way that it will be free-moving and safe, but also detachable. The materials of the bearings and beam need to be discussed. Dr Baruch suggested that the bearings can be made, which would mean that it would not be as heavy as purchased metal bearings, and this would obviously have the effect of being cheaper, suggesting that the bearings could be made from a wooden disc encased in polystyrene. It is felt that this is a bad suggestion because the point of these bearings is that they need to suffer the brunt of all the forces acting upon the opening and closing of the jaw. The bearings do not need to be overly large, and 68mm is the largest diameter that would be suitable for this application. The 68mm bearings that were found on the website rswww.com had a width of 15mm. Each of these bearings weighs 191g so a pair would be 382g. However, these bearings will be of considerable quality and are, if compared to a bearing made from wood and polystyrene, the only real choice. The weight issues are all well intended but if the bearings are connecting the top part of the head to the jaw, and the top part will be the main support for the head as a whole, then the weight issues of the bearings are inconsequential. The beam connecting the bearings, however, will need to be accounted for in the weight limit, as it will go through the bearings. If the weight limit is 5kg then that means that the sum of all parts hanging down from the bottom of the top part of the head cannot be greater than 5kg. The bearings are the connection between the top and the bottom so that means that the bearings should not carry a greater load than 5kg. A wooden broom handle will be employed as the beam. If, however, the wood is too brittle a substance to place such a large weight on a small beam, it has been decided that an aluminium or a titanium beam will be used, as these are the least heavy of all metals prevalently in use today.

For ease and speed of building, the head will now be made from a chicken wire frame wrapped in papier-mâché covered in rip-stop nylon and filled with silicon foam. It was felt that attempting to build a life-size replica of the skull using the proper moulding and casting techniques would have taken far too long and that the use of chicken wire would suffice in this application. The papier-mâché will give some holding strength to the silicon foam, which will provide most of the strength that the head will require. The nylon will be the outer skin and will be picked for the colour that the head will be or painted if the natural colour of the nylon is not a suitable colour.

Potential Points of Failure

There are three potential places where the head will fail. The main point is the pivot. This will need to be very strong and sturdy to survive all of the forces that will be going through it when the jaw is opening and slamming shut. If it is not secure enough when it is activated then it could throw up a load of problems like that the jaw is not on straight, or that it is too fragile in which case one slam too many could shake the jaw off. Another point is that the cam may over or under shoot every time. This overshoot may not be much and in the short term may well not be a problem, but an incremental change of its zero-position could lead to the jaw being half open in its resting position, which would simply be incorrect. The last point of concern is simply that over a long period of time, the more the jaw slams shut the more damage the mouth will sustain. These problems are not insurmountable. The head will be constructed such that it will be filled with silicone foam, which gives massive internal strength. The pivot will be in a hole that goes through the foam so the foam will support the pivot, while allowing it to move. The cam issue can be resolved by rigorous testing to limit the over/under shoot so that it is as small as possible and then adding a crank to move the cam at will. It is possible to use a binary optical encoder to get a more accurate reading of the turn of the cam, but that would add great complexity to the electronic side of the head, as well as being costly. The final issue can be resolved by including shock absorbers like extra springs in crucial positions and building particular parts that are at risk from rubber.

Final Mechanism

The final mechanism to be used is demonstrated in *fig 2-5*. These pictures were taken using a digital camera once the frame had been constructed. They are merely to demonstrate how the mechanism will work and where it will be placed within the head.

As there will be a lot of force going through the model, which will be repeated on a regular basis, the base for the model will need to be quite strong to accommodate such force. Therefore the head will be mounted on a back plate made from wood using 7 hooks attached to the top par of the head. The hooks will be placed on the head with three on each side and one at the top in the middle. This will provide a lot of stability to the model and should keep the head attached at all times. The plate can be attached to the wall using another set of hooks with one hook in each corner. This should provide enough support to keep the head attached to the wall.

This chapter has described in detail various different methods that could be used for a grand scale model before deciding on one particular way of achieving that end. This chapter went on to explain that the grand scale model was far too ambitious for the limited scale and budget at our disposal so only a small number of movements were chosen of which this project will only construct one, being the jaw. It went on to describe a number of different ways of moving the jaw before deciding on one method that will be carried out. It gives graphics to show how all of the mechanisms detailed will work, of both the grand scale and cut-down versions. It also describes the method to be used in the control of the jaw as well as some places where the project could fail.

The next chapter details the physical side of the project work and explains what was carried out in the building of the model.

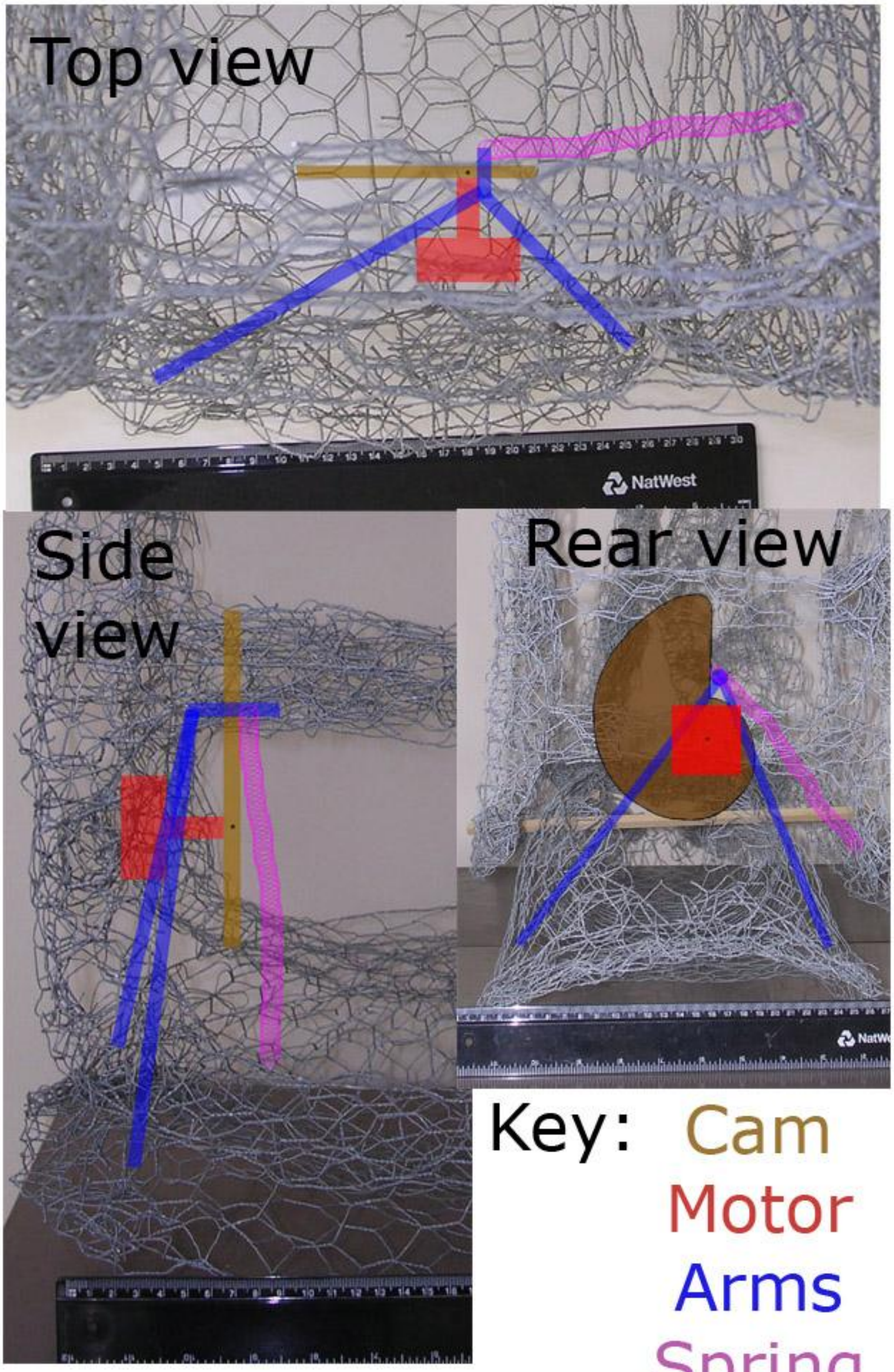

Fig 2-5 – Top side and rear views of the jaw mechanism

Chapter 3

Construction

This chapter will describe the processes that went into the construction of the model including the implementation of the design, the problems that arose and the ways in which they were overcome, and the compromises that were made during the building process.

There are two ways of looking at the creation of the model. While we are creating the model on behalf of the Department of Cybernetics, we are also looking at the fact that animatronic models can be constructed from a variety of materials, and often on a limited budget. A limited budget is all we have so with this in mind we intend to see how feasible it is to make the model using bits and bobs found in convenient places.

Construction Techniques

Papier-mâché test

The design brief states that the model will be built using papier-mâché techniques, therefore a test of the different methods of utilising the form will be conducted. The two main and cheapest techniques are to use flour and water, and the other to use wallpaper paste (McDonald [no date]). The advantage of the flour and water mix is that it is the cheapest way of creating papier-mâché. The advantage of the wallpaper paste is that its strength when dry is vastly superior to the flour and water mixture. The flour and water method is made by mixing 1/3cup of flour with one cup of cold water, all poured in to 5 cups of boiling water, mixed and left to dry. The wallpaper mixture was created by buying sachets of pre-made mix that simply needs to be added to water. The chicken wire had already been procured so two small tubes and two different mixes were made. There are also two different methods of applying the paste: to dip each strip of paper into the mix and layer it on to the tube; and to use a small paintbrush to apply onto the dry paper on the tube. The flour and water mix was applied to one tube using the brush technique, and the wallpaper paste mix was applied using the dipping technique. The results of the experiment revealed that the wallpaper paste mix dried quicker and stronger, and that the brush technique gave a smoother finish to the effect. Therefore it was decided that the papier-mâché we will use will be the wallpaper paste mixture, applied with a brush.

Constructing the frame

Seeing as the budget is limited it was decided that simply using chicken wire with extra wood/polystyrene support would be sufficient for the requirements, so it was from such that we constructed the frame, using wire cutters to get the amount of wire needed, and moulded using glove-protected hands. Using pictures that had been downloaded from the internet as a guide, the chicken wire was moulded to as accurate a degree of realism possible. The jaw piece had a second sheet of chicken wire and a small block of polystyrene placed inside for extra support. The jaw was covered in papier-mâché and left to dry, three layers were applied in this manner. When the final layer of papier-mâché had dried, a layer of rip-stop nylon was applied. This is to give more of an impression of realism as the nylon gives a smoother finish than just the paper, which invariably gives way to small ridges in the paper as the wallpaper paste makes the paper slide around.

The maximum dimensions of the frame of the skull were 844.8mm x 307.2mm x 460.8mm. The dimensions of the motor are 43mm x 43mm x 40mm. The maximum dimensions of the cam are 140mm x 100mm x 10mm and it will raise the pin by 65mm. The spring is 70-130mm long depending on where the jaw is in its cycle. Two bearings were used for the pivot which had an overall diameter of 62mm, an internal bore diameter of 35mm and was 14mm thick.

Control subsystem

The electronic circuit is being designed around a 555 timer running in monostable mode. The motor that was chosen is a geared motor that was adjusted from running at about 2000rpm down to 40rpm, and provides a considerable amount of torque. A motor running a 40rpm means that it simply has to run for 1.5secs and therefore a pairing of a 62kΩ resistor and a 22µF capacitor for a 1.5004sec run-time. The motor was tested for the time it takes to complete one revolution by marking both the gear and an arbitrary point on the motor such that a complete line is formed over the edge of the gear when the gear has turned exactly one revolution. The motor was arranged in the 555 circuit with the above pairing of capacitor and resistor so theoretically the motor should turn to the point where the line is formed. However, things are never quite as simple as this and it became apparent that the motor runs for just over the calculated time. A program was being used that could calculate the output pulse of the 555 depending on the capacitor and resistor pairing so it was then attempted to find an appropriate timing for the 555 using different pairings, however it was never correct to a usable level. It was decided that the error of the gear angle was calculable as a percentage and therefore a new pairing could be established to correct the 555 timing. When the new pairing still did not give a satisfactory response, but was still only a small degree out then another new pairing was tried. At this point it was discovered that the length of the trigger pulse that was activating the 555 had an effect on the length of the output pulse. It was argued, however, that when the head was finished and complete, the trigger pulse would become uniform, as opposed to connecting two wires to simulate the trigger, and therefore could be calculated and accounted for.

However, while pairings of resistors and capacitors are described within various handbooks, it was realised that attempting to achieve an exact timing for the requirement is not the correct way of going about this kind of application. Instead a better way of achieving the result can be utilised.

Improved Control Subsystem

It was suggested that Mr Rod Hine, of the Department of Cybernetics, be spoken to about an alternative as he is one of the experts in electronics within the department. He suggested a simple mechanism that can control itself and turn itself off when it has completed one full rotation. It works by implementing a relay to activate the motor itself, while the relay is run from a control circuit. The relay is set in a circuit where there is a push button and a normally-closed microswitch in parallel to each other. The microswitch is physically positioned on the eccentric cam so that the switch is closed when the cam is at its resting point. This would have the effect of being activated when the button is pressed and remaining active for as long as the cam is out of its resting point. However, the motor is rated at 12V so this is the rating of the relay in use. This becomes problematic when it is taken into account that the controller runs at 5V; the threshold for the activation of the relay is 6V. Another meeting with Mr Hine was made and he gave me the design of a circuit incorporating a 7805 voltage regulator connected to the 5V controller and a transistor connected to activate the relay. The controller will be one combined controller that both parts to the project will have a part in programming so the actual chip to be selected will need all of the functions that either one of us require. For his eyes, Gareth needs 4 8-bit ADC inputs and 4 sets of 8-bit output pins. The jaw section of the head will only actually need one output pin, which will also be connected in parallel to the microswitch and push button. This would have the effect of being able to activate the jaw with a high output voltage from the output pin as opposed to just having to press the push button, thereby allowing for multiple methods of activating the jaw. With such requirements for a controller then there are no better solutions than the incorporation of a PIC microcontroller, as this family of microcontroller is available with ADCs and timers built in to them.

However it is at this point in the project that it becomes apparent that the jaw section of the project has to go it alone, with Gareth continuing separately. The two sections will need to communicate to indicate to each other that it is about to activate and this can be achieved very simply using the input/outputs of each controller. The jaw section has a pin which is connected to the outside world; it is this pin that the push button will be connected to. It is also possible to connect the output of Gareth's head to this input pin so that the jaw will activate on Gareth's command.

Cam Construction

The next task that was completed was to make the cam and the arms. One of the bits and bobs we found lying around was a large board of MDF, from which it was decided to craft these parts. A template of the cam can be found in *fig 3-1* below. The template of the cam was created by establishing the angle over which the jaw will open, which was decided to be about 250°. Then it was established how far the jaw will open and this will be the longest side. This length was decided to be 65mm. A pivot point was established and a circle drawn around the pivot to ensure that there would be enough space and support to place it onto the motor spindle. The angle of movement was drawn in and this was divided into a suitable number of steps. The length of 65mm was divided by the same number of steps to generate a smooth progression where every step around the circle was proportional to the distance travelled outward from the centre. The overall effect is that of a vague 1-rev spiral whose start point is 65mm from its end point to allow the pin to be pushed away from the base at a uniform rate, and a straight line to let the pin fall straight downwards under the exertion of the spring. The zero-point of the cam is marked in the diagram as 0_p. Once the cam was cut out a small hole was made that the spindle of the motor fits into, before being covered in parcel tape to give extra protection. It was then glued onto the motor using epoxy resin mixture. Two touch sensors were procured to a) feedback to the controller and b) override the relay to allow the motor to keep moving when the cam is away from its zero-position. These were then glued to a large metal kebab stick that was being employed as a frame, which in turn was glued to the back of the motor to form one large piece attaching motor to cam to touch sensors.

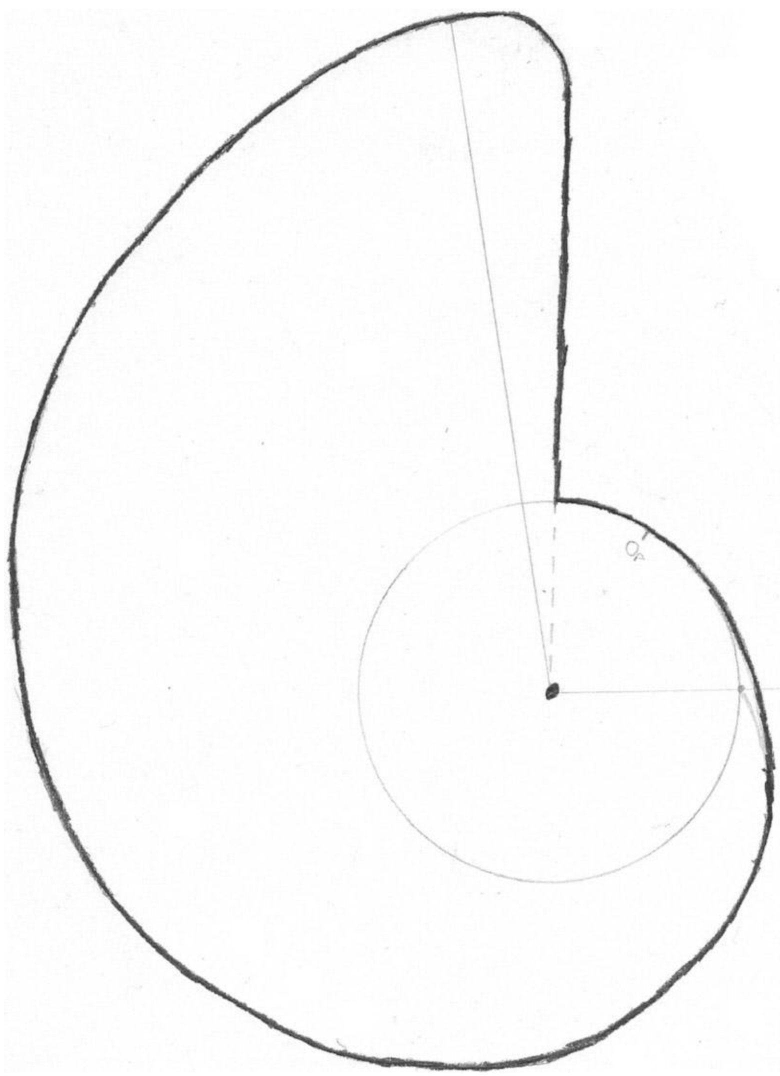

Fig 3-1 – Actual size image of the eccentric cam

Parcel tape was also used to cover the tabs of the touch sensors to reduce frictional wear on the cam. A photo taken of this piece can be found in *fig 3-2* below.

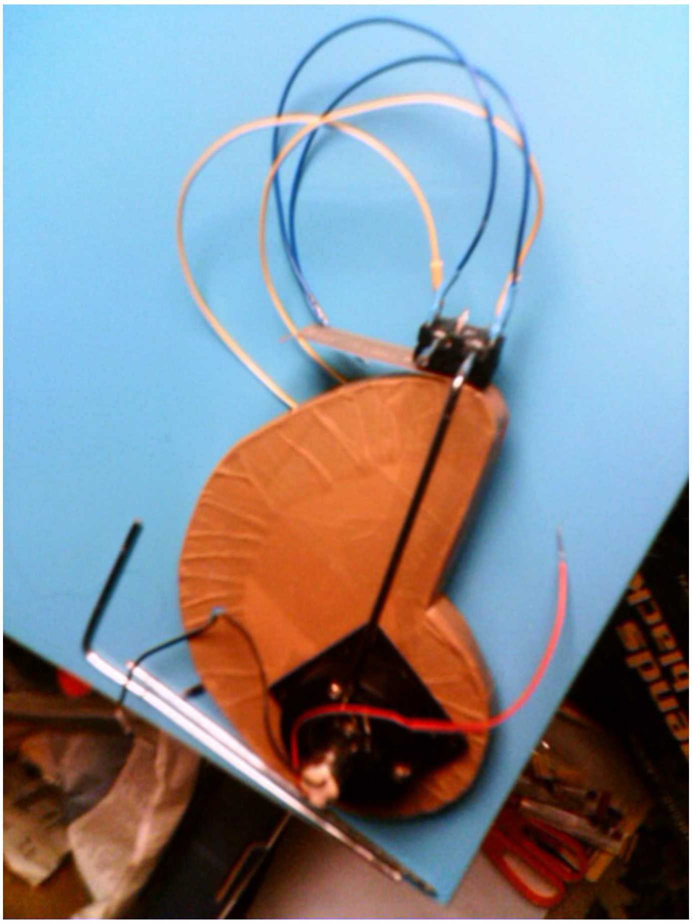

Fig 3-2 – The cam/motor/sensor piece

Controller Design

The creation of the controller is the next objective. Knowing the most parts of how the circuit will be made I am able to construct a basic circuit diagram which will be used as the basis for the controller. This can be found in *fig 3-3* below.

There are many various different controllers available, however the PIC16F84A (PIC) was chosen simply for the fact that the supplies and facilities are available within the University to program and develop the controller based on one of these, remaining in line with the point of using things that were close and easy to procure. The PIC was programmed in a variant of the C programming language and it was at this point that the workings of the head were finalised. The PIC will have two inputs and one output. The output is connected to the transistor to activate the relay, in turn activating the motor. One of the inputs will be connected to the outside world as the switch that can be pressed to activate the jaw; the other will check the status of the touch sensor placed with the cam. The program will constantly check the cam and the program will pause if the cam is in motion. If the cam is not in motion then the program will be working out when it will activate the jaw. This will be done using a timer. The idea for the jaw is that it will not be activated at a uniform rate. One idea that was had was to incorporate a random number generator and have the jaw mechanism run when the response number fell into a certain range. Random number generator libraries are available even for the PIC16F84A with its limited capabilities, however it was felt that a simple pseudo-random response that was identical in its execution every time was enough for the purposes, as that would keep processing down and keep the program under a certain level of control. An 8-bit integer can have a maximum value of 255. It was decided that if one unit counted one tenth of a second then the counter could wait up to 25.5 seconds before jaw activation. If the counter was initialised at some low, arbitrary value with no relation to 255, say 19, and double it and modulate it to within 255 every time and that could generate the pseudo-random response. The values of the timing function will follow the same progression every time the controller is switched on but the effect is that the jaw would snap, wait, snap, wait twice as long, snap, then the pause would be significant and then it would snap twice in quick succession, wait for a bit, snap, and so on. A basic program that can achieve this is created but can be refined when the circuit is working.

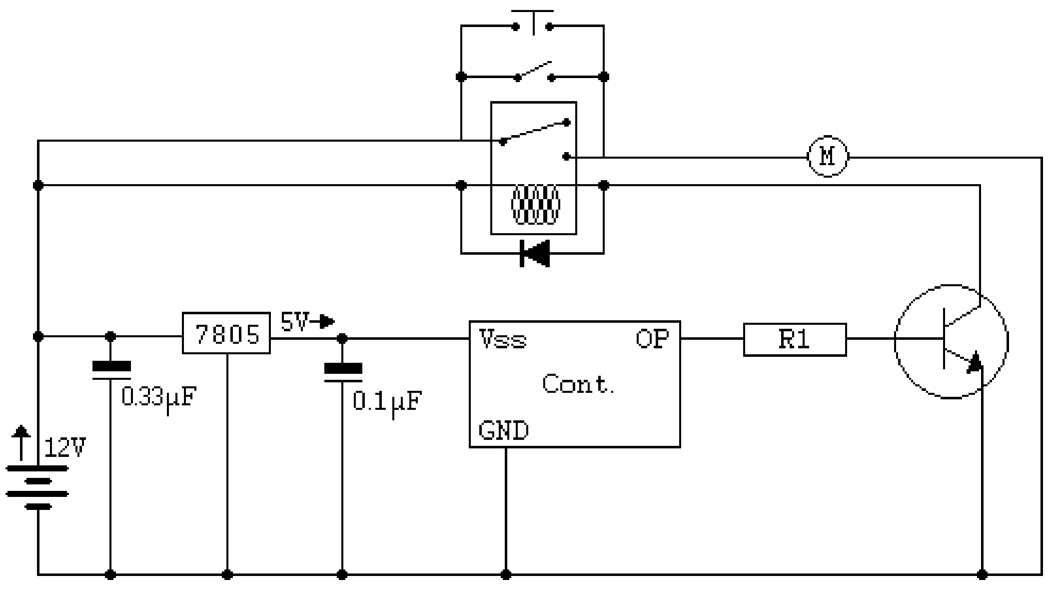

Fig 3-3 – Circuit diagram for the controller

Circuit Design

Now that the controller is programmed it should be implemented into the circuit. Following on from Mr Hine's suggestions some research is carried out into the idea of using transistors as switches. Hewes (2006) details all of the steps that need to be taken to develop a transistor switch, including the selection of the related resistor. This can be found in *Appendix A*. The transistor chosen was a BC337 with a 2k resistor to pair. A diode will also be required within this circuit. As the relay switches off the current being used to activate it will need to run off. The diode would be placed parallel to the relay in circuit to ensure that the current does not go in the opposite direction to the flow of electricity, which would be very damaging to the relay. The capacitors used in conjunction with the 4MHz oscillator were both rated at 22pF. There was 4.7k pull-up resistor connecting the MCLR pin of the PIC to the 5V supply.

These are all the sundry parts we need to make the circuit, and a schematic of the circuit was created using EAGLE v4.14 (freeware version). This can be found in *fig 3-4* below. Also included are three LEDs and their current-limiting resistors that are employed as outputs in the program to show which part of the program is being executed at any time; and the push button that triggers the output on demand.

The creation of the circuit was definitely a learning experience, not least because of the distinct lack of formal electronics teaching on this researcher’s part. Most of the skills used in this part of the project were picked up as they were needed, which meant that a lot of time was spent working out what was required at any given moment. As a result, it took far longer than originally intended to achieve the desired outcome. Starting with a breadboard and an assumed list of components, the initial circuit was created. When this did not work Mr Mark Tympalski of the Department of Cybernetics was consulted for a few tips. He pointed out that some truly basic principles were being left out, for example the basic program was not executing, which turned out to be due to the fact that the oscillator was not attached to its controlling capacitors. This is one case in point where the lack of formal teaching slowed the project almost to a halt. Mr Tympalski quickly pointed out how to address the problem and thankfully was at hand when similarly basic problems came to light, the vast majority of which were blamed on items that were not deficient in the slightest. However, when the circuit was completed within the breadboard it was time to solder it in to strip board, which was not nearly as problematic as thought. When this was finished and bugs ironed out it was time to make sure that the program works as it should.

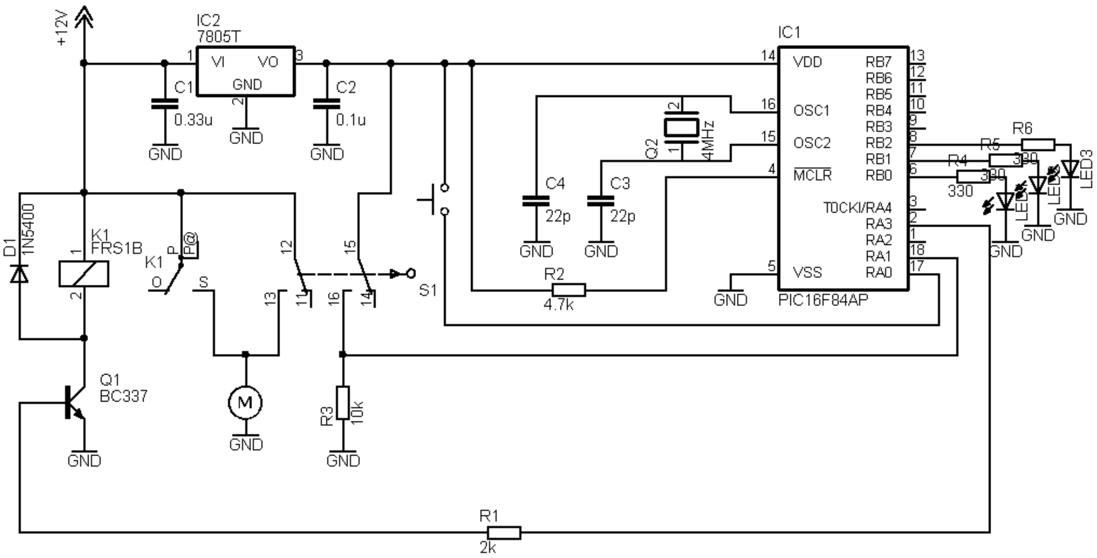

Fig 3-4 – Circuit schematic

Program Design

The program has to be able to activate one output based on a signal from either an exterior source or a software-based variable timer. The original program split this into 3 sections, one to check if the button has been pressed, one to wait 0.1 seconds and one to activate the output. It was worked out that the 0.1sec delay would have diminished the reaction time of the button and that the job could be done in a more efficient way. Subsequent variants of the program evolved the ideas and rearranged the commands to find the optimal code listing, but all of these had their problems. The programs could either react efficiently to the push button at the expense of the variable timer, or the timing function was too intense to react properly to the push button. Finally it was worked out that the program could use nested for loops to act as a variable counter where the main loop was counting to a multiple of the activation variable, with a nested delay inside that loop that was also counting a much shorter multiple of the same activation variable. This would have the effect of counting to a multiple of the square of the activation variable as opposed to just counting to the variable giving the timer a much greater variance of timings between activations. The push button works in this program by using a check variable reading the input pin around the innermost for loop delay. This is counting such a short delay that the button will be picked up in every circumstance. The reaction to the push button activates a check variable which then invokes the break subcommand to jump out of the loop. This does still contain programming delays and the reaction to the push button is not instantaneous, but too short as to be noticed by the average human reaction time. A full program listing can be found in *Appendix B.* However, this was the optimal set up for the program and when it still did not work an investigation into the workings of the PIC began, explained in Appendix C, and also meant the end of the construction of the Allosaurus Head.

This chapter has described the actions that were carried out in the process of building the model from start to finish, including all of the problems that came up during that time and how those problems were overcame. This includes the problems that were encountered in the building of the frame, creating the cam and the mechanism, and designing and building the control circuit. It also gives a circuit diagram for the controller and describes the programs that were made for the controller and the final test program run before it was decided that the project end.

The next chapter will look at how the construction in its final state compares to what was requested in the original objectives.

Chapter 4

Review of Project Objectives

This chapter reviews whether the project completes the tasks described in the objectives by quoting the objectives paragraph found at the very top of the document and then relates the finished work back to it to explain whether or not that particular objective had been met, drawing on some of the lessons that had been learned along the way.

About midway through the project work my partner Gareth Knight had to break off the work due to temporary financial constraints. As a result this meant that only a part of the project would be completed and this chapter deals with reviewing the part that was finished with original objectives.

The objectives were described, as follows in bold:

"The objective of this project is to create a life-size dinosaur head based on a dinosaur that once existed."

The Allosaurus was originally found in the deserts of Utah, as was described in Chapter 1. All that is known of the dinosaurs including the Allosaurus chosen for this project comes from nothing but their bones found through archaeology. There is nothing to indicate exactly the form of soft and cartilaginous flesh or the colouring of their skin. Generally it is believed that only mammals have hair while dinosaurs along with other reptiles have scales, though a recently discovered fossil was that of a feathered dinosaur. However it was decided for this project that the skin should be more towards that of a scaly outer as that would be the easiest to achieve. This was represented by the stiff papier-mâché surface. In this area the objective was completed though recent models from Kokoro indicate that they have adopted latex foams for the skins which makes them convincing to the touch. However when it comes to the colouring of the skin then it all comes down to guesswork as it would never be possible to discover the true colour of the dinosaur without going to extreme lengths that are beyond the realms of possibility at this time. However the guesswork could be quite educated. The Allosaur fossils were discovered in the Utah desert and given their colouring would vaguely match that of their surrounding meaning that the model should be given a hue somewhere between green and brown.

"The head should make some actions which should be highly repeatable, and should be constructed from lightweight and inexpensive materials. Therefore a compromise will need to be made to find the optimal balance of the mechanism being fast, light, accurate and strong."

The frame of the head was constructed from chicken wire and papier-mâché. This was chosen as being a balance between being lightweight and inexpensive. It could have been achieved using crafted fibreglass which would have been lighter, however it would have been a lot more expensive. Any methods that would have been cheaper, for example wood, would have made the project a lot bulkier and a lot heavier. The motor was chosen specifically for its RPM rating as that was the speed that was required by the project. The design of the mechanism with the cam and the microswitch allowed it to be triggered by a single pulse the controller giving a high level of repeatability from that part of the project. Also, the partnering of the cam with the microswitch meant that accuracy was a given. However the factor of strength in the mechanism is in doubt. It is not easy to tell whether the wheel would have had enough force with which to open the jaw at all, and if it could then it is not easy to tell whether or not it would have lasted very long. The cam was made from MDF and covered in parcel tape so if it was capable of opening the jaw it is highly doubtful that it would have had much in the way of longevity. The force of the jaw running over the tape combined with the switch itself means that the tape would wear away after only a relatively short period of time. Once the tape has worn enough then the MDF underneath would begin to crumble and shrink so as not to be able to close the switch, thereby rendering the mechanism unusable.

"The head should be autonomous and be able to run of its own accord, though there should be some element of exterior control."

The design of the controller meant that the control of the head was self-contained and based on timers. The push button was included and the head did react accordingly. This is, however, the point where the project was let down. The timers of the controller only allowed for such precise control that its resolution was a matter of less than a second, whereas the precision of control required was that of a matter of seconds going up to a minute or so. It is not explained in the documentation of such a shortfall and even when the PIC was sent the program it revealed that only 348 of 1024 program words were being used within the processor meaning that there was more than enough processing power to handle the requirements. The issue could be due to either the compiler, as it displayed a message saying that a certain number of instructions in the program had been optimised without revealing the instructions that were subjected to the procedure, or some unknown hitch within the architecture of the PIC itself. The compiler works by translating the C code into assembler language, which is then converted into a HEX file to be sent to the PIC. The lines of code are optimised as it is translated into assembler and the only way of working out where it has been optimised is to go through that. This researcher knows little about assembler language, otherwise it is what would have been used to program the PIC, so it was very difficult to establish if that was the problem. The same can be said of the architecture of the PIC, though the nature of the problem in that it was able to handle a certain number of loops but could not go any further implies that a mixture of both factors to a certain extent would be the main source of the problem. It is impossible to have known about this problem before the project started and the PIC was chosen because of its versatility as well as the fact that there are the facilities to program it on campus and no new hardware was required. However it should have been figured that this was the case. The PIC16F84A is designed to be a small level microprocessor to handle quick tasks running at a comparative speed to the oscillator timer. It is not designed to be a processor to handle tasks with a lot of dead waiting time.

"The quality of the aesthetic of the head should be realistic enough to be able to place as a museum exhibit, but does not have to be the extremely high quality of, say, a Jurassic park model."

The model was only taken so far as to have a frame of the model coated in papier-mâché and coated in rip-stop nylon. Great care was taken to ensure the correct dimensions as provided by the research on the dinosaur in question. This allowed us to make the dinosaur as realistic as the materials allowed. Having used it to create such a model, it has been found that the combination of chicken wire with wooden supports can be quite versatile with as great a quality aesthetic as the constructor cares to attain.

“The system of control should be placed within the head.”

Again, as the project was not completed it is not possible to say that this objective was achieved, however as the designs suggested that the controller and the mechanism were placed in the upper section of the model, this was as close to the objective as could be achieved. Given that the motor would have to be placed within the head to be able to actuate the jaw, added to the fact that the circuitry created is of such negligible size and weight, it is easy to say that the control system could be placed within the head.

“The documentation of the project will be placed into the public domain to form the basis of other projects to come in the future.”

Even though this project was not completed, a lot of lessons were learned and an updated design and methodology will be described below.

Some of the main lessons learned from this project stem from the problems that arose with the controller. It was decided that in future a processor should be chosen that can definitely handle all the requirements, which should be checked out in advance of the beginning of the project. Also it is not advisable to simply choose parts like the controller purely for the ease value of having the facilities on site. The simple suggestion to rectify this issue is to alter the clock speed, as will be described in greater detail below.

The future of the project is to add to the mechanism created and build towards the grand design described in the beginning of Chapter 2. This could be done in a modular approach so that the next person to undertake a part of this project could, for example, build a portion of the neck and continue in that direction.

This chapter reiterated the original objectives and relates the project work back to them to explain whether or not they have been achieved. It also relates some of the lessons learned from the work that was achieved.

The next chapter is a description of how the model should be built based on what has been done for this project.

Chapter 5

Revised Design

This chapter describes an updated alternative design to the mechanism that was created taking into account all of the problems and issues that arose during the creation. These were real problems that any development programme could face. The chapter explains why the changes were made. It will also compare the updated design to the models that do exist.

Mechanical Redesign

The original design when implemented was a partial success but it has been shown that there are many aspects where it could be improved. In this chapter the main considerations of the speed of motion and the maximum weight are factored in to the design but can be built upon. The main alteration of the design proposed is with the mechanism used to create the motion. Some of the main factors that stem from the previous design mostly come from the usability and repeatability of the design mentioned. The old design was based around a cam and a spring, with the cam rotating exactly one revolution to open the jaw and stretching the spring, and the release of the spring used to snap the jaw closed again. The usability queries stem from the fact that such a mechanism is doing more work than is really required and the fact that the use of the spring may well end up shaking the model apart. The repeatability factors stem from the issues relating to the construction of the cam, being made from a material that is prone to falling apart when used in such ways. While this is relating more to the construction side of the project, a good redesign will eliminate such problems arising to begin with. After plenty of consideration, it has been decided that the model should use the system incorporating the motor and mechanism in the rear of the model to act as a counterbalance as a method of closing the jaw. The basis of this mechanism is that the motor will be set into the rear of the jaw to add to the weight at that end, with a single gear around which is thread some string, strong fishing line is ideal, then as the motor is powered and the gear turns, it will pull on the string, raising the rear side and opening the jaw. This can be achieved by calculating the weight of the jaw on each side of the pivot point then adding some filling material to ensure it balances out evenly, before the motor is added. The fine balance over the pivot would allow for only a small amount of force required to open it; the power required to open the jaw would not need to be great, just enough to lift the extra weight of the motor essentially. A limit switch would be used near the top of the range of movement, which will send a signal to turn off the motor. This will leave the motor raised and with nothing else to keep the motor in place, gravity would take control and the jaw will close. As the jaw closes it should be noted that the string will unwind and turn the spindle of the motor which will in turn generate a current. The electronics side of the project can be designed to incorporate this current, which could be used to actuate another effect, for example a sound sample of the dinosaur roaring could be implemented. With this in mind, the motor will not need to be powerful, firstly because the only force it needs to move is actually just the difference of weight in the rear compared to that of the front, and also because the string needs to unwind itself when the motor stops receiving power. The gear will be created to contain a large, angled groove with which to collect the string and ensure it doesn't slip over the end so to maintain correct movement. A second limit switch will be implemented at the bottom end of the motion, where the jaw is closed, that will send a signal to the controller to indicate that the jaw is ready again to be opened.

Redesign Limitations

There are a few limitations with this design of the mechanism. Firstly, the weight balance on each side of the pivot needs to be perfectly attained. The weight at the rear side of the jaw will need to be greater than the front by a margin that allows the jaw to close swiftly and with conviction, for which a greater mass at the rear would be required, however the weight at the rear should not be so much that a simple ungeared motor should be able to move it. The motor should be chosen for its weight and power considerations, in that it does not need to be strong and powerful, but neither does it need to weigh a great deal; a simple motor designed for small models should be sufficient. The idea is that the weight of the rear of the jaw be enough to unwind the motor so a weight at the high end of the motor's capacity should be created, however that can only be decided on the procurement of the motor. Shock absorbers will need to be implemented to ensure that the force of the jaw closing, and any subsequent damage, is kept to a minimum. These can be implemented in the front of the jaw and possibly dressed up to look like teeth. Other things to consider include taking great care when designing the electronics to make sure that the current generated when the jaw is closing is diverted away from the microprocessor in charge of the model's behaviour. This can be achieved simply through the use of diodes and relays. The point at which the string is attached is important, too. It is suggested that above the limit switch, the string split and have multiple points where it is attached to the top part of the head. This will spread the force of the jaw pulling on the top of the head, which will limit the potential for damage to that part of the model. Also, care should be taken to ensure that the motor and string should not be visible when the jaw is open. This can be done by covering the rear of the mouth section with dark fabric or extra papier-mâché.

Balance of Issues

A point made earlier about how no mechanism can be fast, light, accurate and strong is one of the main fundamental factors in this project, and it is felt that this mechanism finds an appropriate balance within those factors; the size of the gear will be small but can be calculated with the length of the string to achieve a good speed for the movement of the jaw. The factor of weight is somewhat negated by the fact of the balance over the pivot point, and it is felt to be far from a challenge to keep the jaw within the original 5kg weight limit as set in the brief. Accuracy is determined by the length of the string and the position of the limit switches, so it is essentially a given from the beginning of this design. The issue of strength is the weakest of the factors, however as long as the motor is strong enough to carry the rear to the top and not provide enough of a challenge to gravity to close it again, that that will be considered strong enough for the requirements.

With regards to the materials used for the creation of the model, it is felt that this materials used in the construction described above will be satisfactory for the new version of the mechanism. The chicken wire frame and wooden supports are strong enough to withstand the moderate forces running through as the jaw closes, and lightweight so that it easily remains within the limit of 5kg as set out. A slightly overweight rear side will help the jaw close convincingly, providing it remains within the abilities of the motor, and certain steps can be taken to ensure that it does not cause any damage, for example by using springs as shock absorbers on the front side.

This means that the construction of the model will remain in the realms of being cheap and lightweight to create.

Controller Redesign

The controller is another area where redesigning will be beneficial. The limitations of the controller that was constructed were unknown as it was being created, so this is another place where a good redesign will eliminate problems from arising to begin with. The main point where the previous controller failed was with its endless counting gaps to try and establish a variance between jaw actions. This can be eliminated by simply lowering the speed of clock-timing oscillator and removing the need to count endlessly. The requirements of the controller are to be able to intercept the signal of the push button within the space of the human reaction time, while also calculating the length before the next automated snap of the jaw if the button signal is not received. Between the needs of capturing the press of the button and requirement to react within the span of the human reaction time, a frequency of around 50Hz will be more than sufficient, compared to the frequency of 4MHz that the old controller was running at. This is a factor of 80000 that the previous controller was counting that was technically unnecessary. This is easily achieved by implementing a resistor/capacitor setup to the OSCIN pin of the PIC used in the construction.

Sound Implementation

The sound effect could be implemented by using a DPDT relay, so that one connection leads from the controller, and the other connection leads to the sound module, which is isolated from the rest of the circuit. The principle is that as the motor receives power, the slack of the string will be pulled up and the jaw will rise. As it reaches the top it will hit the limit switch, which will both deactivate the motor, and switch the relay so the motor is connected to the sound module. As gravity causes the jaw to close, the motor unwinds through the string and all current will be diverted to the sound module, which then makes its noise. It will need to be isolated because if the main connection to ground exists then the device will not work correctly. The sound module can be bought in and a standard sound effect of a roar can be used. The second limit switch, at the bottom of the jaw motion, will reset the relay so it can receive power again for the next time it is required.

One possible issue with this is the case that the motor may keep turning through its natural forces after the jaw has hit its resting position. This can be remedied by allowing a delay timer to let the motor run its course before switching the relay back to the main setting. There will be plenty of slack to ensure the motor doesn't swivel the string round to the other side and begin to open up again. The sound effect will remain short so that it is finished in time for the jaw to be closed, to eliminate the effect of the sound being made while the mouth is closed, which would simply not be correct.

The advantage of using the limit switches is that the controller will always know which way the jaw is supposed to going next, eliminating the need for such timers. When the motor is activated it will pick up the slack of the string, but the motor will keep going until the upper limit switch is hit, which is when the motor will stop and the jaw will close. *Fig 5-1* below shows and describes how the mechanism will work.

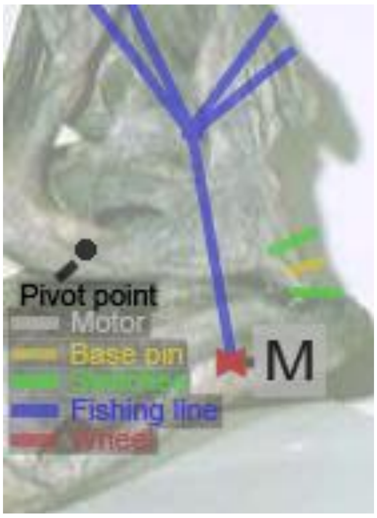

Fig 5-1 – Graphic of updated design

The image *Fig 5-1* above shows the rear of the skull of the head to be copied, with colour-coded representations of the parts of the mechanism as described above. The base pin will be required to activate the limit switches at each end. What is not shown in the diagram is the filling required to balance the weight, as that will only be established when the head is built and the calculation is possible.

There are a few points in the original design that are not changed, however. One of those is with the main interface between the model and the outside world. The design was set to run on a variable activation timer, with a push button to activate the model on demand. This is one point that is already fine and suitable and that does not need to be changed. Another point that remains from the original design is that of the stand. The original design stated that the model would hang from the wall on a backboard of wood hung by an array of hooks by the back of the top part of the head. It is felt that this is more than satisfactory to keep the model in place.

This chapter has described an updated version of achieving the jaw design incorporating what has been learned from the building of the project as a whole. This includes updated versions of achieving the base and armature and method of moving the jaw. It also contained a diagram of the new version detailing the workings of the updated mechanism.

The next chapter summarises the work carried out as a whole and describes the conclusions drawn from the project overall.

Chapter 6

Conclusions

This chapter describes the conclusions that were developed from the undertaking of this project.

Starting out

This has been a project of many parts. It started out to create a life-size animatronic model that could be used as an exhibition piece. There were two people working on it to allow a greater scope and have more functions within the head. Initially it was very difficult as we were trying to find useful information about previous examples of animatronic models on which to base the project. The material available is very sparse and the selection there was to choose from are all brief descriptions and images of either projects of a much grander scale, where there was a team of people for each individual part of the production, or the examples of the ancient automatons, which were all surveyed in the opening chapter. Never was there a detailed example of how the machines work or were constructed as it is often the case that such information is kept as trade secrets and so has a lot of protection from the creative studios owning the copyrights. At that stage in the project the two of us had divided up the different parts of the head that we wanted to animate between us, then set about developing designs and mechanisms to be used to create the different types of movement. As there was not too much useful information available the designs we were creating were not necessarily up to scratch in terms of the quality of graphic or efficiency of method for the ideas we were producing. Also it was decided to design the model such that it could have been built by only very small number of people in a reasonable amount of time. This led us to strip down the grand design and select only two main sections of the models and focus our attention on achieving a quality result for these specific mechanisms, with this part of the project focusing on the lower part of the head and making a jaw mechanism, and the other part of the project focusing on the top part of the head and making an eye mechanism. These designs were finalised such that this section of the project looking at the jaw would work using an arm on a spring allowing the jaw to snap shut. An eccentric cam powered by a motor would raise the arm and when the end of the rotation was reached the arm would snap closed under the force of the spring.

The need to strip down the project is one area where a large lesson is learned, in that a project should always stay within the boundaries of one's abilities, even despite the fact of the limited budget. We had ended up being carried away with the grand scale design that it wasn't until it was pointed out, that we realised we should rein in our plans and keep the project in realistic realms of being a project we could actually build.

Construction

The construction process began with the creation of the chicken wire frame which was then covered with papier-mâché. As this was being carried out, the other parts of the mechanism were being researched and selected. As we were taking the approach of it being a home-made type of model, we regularly used parts and materials that we either found or bought cheaply. Some of these were suitable, such as the deconstructed pine draining board and the block of polystyrene used as support inside the chicken wire frame. However also discovered in a storage cupboard was a block of MDF that would go on to be used as the material for the eccentric cam. However as the construction of the project was underway the top part of the head began to fall behind as the student responsible for that section had to drop out of the project for personal reasons. That meant that the only work being done on the project would be this section. As the work continued into the creation of the jaw many things were learned on a personal level as useful skills improved, such as knowledge in the fields of electronics, programming, timekeeping and writing skills, though the vast majority of these lessons were learned the hard way through mistakes being made and taking in the issues that arose as a result, especially the electronics. With no formal electronics teachings this part of the project proved to be particularly problematic and all of the techniques used in this project were learned as they were required. This case is less so with the programming, as that is a skill comes naturally for this researcher. As for the timekeeping and writing skills these are always things that can be improved upon to better oneself. The work continued until the points were reached with the hardware and software where the software did not work no matter how it was written or the approach taken, which is when the nested loop test program was written that showed up the flaws in the PIC itself; and the hardware required the top part of the model in which to place the mechanism, which in itself would have meant waiting for the other student to reach a point at which it could be used, something he admitted would take a while to complete, if ever. Therefore an end was called to the project at this point.

Points of Issue

In hindsight some of the bad parts are easy to spot, for example the fact that while the mechanism is sound in theory, a weight limit for the jaw of 5kg being pulled over a cam constructed from MDF is not very sound in practice and it was expected to have crumbled apart after only a small percentage of the lifespan that was being targeted. Another example would be that of the PIC. While such a flaw in a system would not be documented, as it is a pretty innocuous flaw in a system that was not designed to be run in the manner in which it was here, it is easy to recommend that next time a smaller oscillator be used so that the processor is not counting almost endless dead-time. Both of these examples come into the category that they were used simply for the factor of convenience, which, while being one of the factors we were looking at, did show up some of the flaws of such an approach. The facilities for the PIC were situated on campus as it is part of the undergraduate studies. When it came to the point where the oscillator was selected the technician recommended that a high speed oscillator should be used as that is the setup with the undergraduate tasks. This turned out to be the point where the controller failed, as the speed of the oscillator is what made the counter need such a high count to achieve the same result as a much slower oscillator. However not all of the project could be considered to have failed. The electronic circuit in which the program was implemented achieved its task more than satisfactorily, and the rest of the hardware certainly would have held up to the task with the motor able to repeatedly turn and raise the arm, cam notwithstanding, and the frame with the papier-mâché would have provided more than enough a pleasing aesthetic and exterior support, particularly with the pine and polystyrene support. This gives a number of things that can be built on for next time. Firstly this project has stated the ideas for a grand design that would allow for a number of different movements and create a more lifelike model. One suggestion that could be made would to not use latex as the base material, as it would be incredibly difficult to create a life-size skull in which to fit all of the mechanisms into. As it turned out, the basis of the wood frame/chicken wire exterior demonstrated decent versatility. However this is not to say that latex should not be used at all as it can be used for its elastic properties to create the skin in places where it needs to stretch. Once this has been refined and the weight of the frame reduced to as little as possible with the structural support and the weight of the individual mechanisms then the final addition that could be made to the design would be that of an articulated neck. At the very early stages of this project when the grand design was being formulated this idea surfaced and would not be immensely difficult to achieve with a set of powerful servos. However this could not be implemented into the head until all of the rest of the details and mechanisms have been constructed and made to work so the design was not really elaborated upon.

The angle of using cheap or free parts and materials was an interesting choice of methodology, and the limited budget we had at the outset ensured that that was the way it was to be built. It demonstrated both positives and negatives; positives in that the actual construction of the model was successful as far as it was completed, and it is felt that the combination of wood and chicken wire can be used to create all kinds of usable frames and structures. However when it came to the controller, it is felt that corners should not be cut. It has been shown that such models can be completed in a "lo-fi", low-budget environment with a moderate degree of success, however the quality of the results are tied to the time and money spent on the project. One particular point of note is with the cam. The material from which it was created was found and used for the reason that it didn't require any cost. MDF is quite malleable and it was easy to create the exact shape required of it, however that same aspect was also its downfall as it is would not have survived as long as would have been hoped from the objectives. The lesson here is that while certain things can be used for minimal cost, they do not provide as great a result as if even a small amount of money had been spent on superior materials. The home environment can provide a large number of items that may well be going spare and could be used in such models, however careful choice should be made when using them as the final piece may be let down by such shortcomings.

Animatronics at Home

Animatronic projects such as this can be done in the luxury of one's home. It does, however, require a lot of time, space and effort. The first thing a person requires is a workroom in which to undertake the project, a space in which to plan and devise, and then to build and construct. Understanding of various different types of mechanisms and ways of creating and controlling movement is necessary to make the animation of the model. The design process as a whole is often the hard part, and when a design has been decided upon it is then to construct it. The easiest and simplest material from which to construct a model, in terms of being able to buy the material, related tools and being able to use it, is wood, which when combined with chicken wire can create a decent structure that can be moulded into various shapes. The next skills that are required are those of electronics and programming with which to create the controller and associated circuitry. While it is possible to create a method of running the mechanisms using only electronics and switches, it can require a higher degree of complication within the circuitry and there are many advantages to having a programmable controller, such as increased versatility within the range of movements and reprogrammability to refine the program once the model has been constructed. The final and most important thing, however, is the virtue of patience. Creating a model can be greatly time consuming and a lot of time is taken up with debugging and fixing things that inevitably go wrong, for example, bits of wood snapping mid-saw, gears being made ever-so-slightly the wrong size, endless amounts of wiring and solder (depending on design), or even just the electronic systems simply not working as intended.

Conclusion

This project has described the construction of an animatronic dinosaur head. It has started with the published literature which is mainly limited to images and brief descriptions of working models. The project has produced designs for the construction of the head and the mechanism to move the jaw as well as how that mechanism is controlled by microprocessor module. It has discussed the options for the head armature and skin and explained the compromises that had to be made. This same approach was also taken in regards to the electric drive and the electronic control systems. These are now documented for the head of an animatronic robot along with the problems and advantages of this approach. It has been shown that the information relating to the construction of an animatronic model is sparse, and as such this documentation will be placed in the public domain to form a foundation on which others can build a similar project.

As it stands the project may not have been a complete success but nothing ever works at the first attempt. However there is enough on which to build and with luck it should succeed in the future.

References

Books

Critchlow A. J. (1985) *Introduction to Robotics* New York: Macmillan

Fuller J. L. (1991) *Robotics Introduction, Programming and Projects*. New York: Merrill

Iovine J. (2002) *Robots, Androids, and Automatons: 12 Incredible Projects you can Build*. 2nd edn., New York: McGraw-Hill

Hall E. L. & Hall B. C. (1985) *Robotics: A User Friendly Introduction* CBS College

Heiligmann R. & Poor G. (2003) *Animatronics: A Designer's Resource Guide*. Illinois: Ian Hunter Publishers

James T. (1989) *The Prop Builder's Molding & Casting Handbook*. Ohio: Betterway Books

Klafter R. D. Chmielewski T A & Negin M (1989) *Robotic Engineering: An Integrated Approach* Englewood Cliffs, NJ: Prentice-Hall

Wise E. (2000) *Animatronics: A Guide to Animated Holiday Displays*, Indianapolis: Prompt

Websites

Anderson P (1996) *Audio-Animatronics*. [Online], Salt Lake City, UT: Persistence of Vision. Available from: http://www.disneypov.com/issue06-7/aa.html [Accessed 12th Feb 2006]. NB This page has its own page of footnotes which can be found here: http://www.disneypov.com/issue06-7/aa2foot.html

Hewes J. (2006) *Transistor Circuits*. [Online], London: The Electronics Club. Available from: http://www.kpsec.freeuk.com/trancirc.htm, [Accessed 17th Feb 2006].

Hooper R. (2003) *Robots in Space*. [Online], Austin, TX: LearnAboutRobots.com. Available from: http://www.learnaboutrobots.com/space.htm, [Accessed 13th Feb 2006].

Ives R. (2000) *Rack and Pinion*. [Online], Maryport: Flying Pig. Available from: http://www.flying-pig.co.uk/mechanisms/pages/rackandpinion.html [Accessed 17th Feb 2006].

Ives R. (2000) *Worm Gear*. [Online], Maryport: Flying Pig. Available from: http://www.flying-pig.co.uk/mechanisms/pages/worm.html [Accessed 17th Feb 2006].

Maxfield C. & Brown A. (1997) *1971 AD to 1976 AD The First Microprocessors*. [Online], Madison, AL: Maxfield and Montrose Interactive. Available from: http://www.maxmon.com/1971ad.htm, [Accessed 13th Feb 2006].

McDonald S. (2000) *Papier Mache*. [Online], [s.n.]. Available from: www.halloweenfear.com/papiermache1.html, [Accessed 12th Feb 2006].

McVey T. (2005) *Animatronic Tyrannosaurus Rex*. [Online], Banbury: Nimba Creations. Available from: http://www.nimbacreations.com/T-rex/T-rex.htm, [Accessed 12th Feb 2006].

Nachtwey P. (no date) *Fluid Power vs. Electromechanical Power*. [Online], Vancouver: Delta Computer Systems. Available from http://www.deltacompsys.com/pdf/fluid%20power%20vs.%20electromechanical%20power.pdf, [Accessed 12th Feb 2006].

Nilsson S. (1997) *Controller Area Network – CAN Information*. [Online] {s.n.], Available from: http://www.algonet.se/~staffann/developer/CAN.htm, [Accessed 17th Feb 2006].

Rubenstein A. (2001) *Giant Animatronic Heart* [Online], Palm Springs, CA: OneDreamDesign.com. Available from: http://www.onedreamdesign.com/illustration/index.shtml, [Accessed 13th Feb 2006].

Sayous P. (2001) *History of the Automaton*. [Online], Paris: T.I.L Productions SARL. Available from: http://www.automates-anciens.com/english_version/frames/english_frames.htm, [Accessed 12th Feb 2006].

Simkin J. (12th May 2002) *Joseph Jacquard*. [Online], Brighton: Spartacus Educational. Available from: http://www.spartacus.schoolnet.co.uk/SCjacquard.htm, [Accessed 12th Feb 2006].

Triesch J. (no date) *Anthropomorphic Robot Head*. [Online] San Diego, CA: University of California in San Diego. Available from: http://cloudbreak.ucsd.edu/~triesch/robotHead/, [Accessed 17th Feb 2006].

Tyson J, (no date) *How Animatronics Works*. [Online], Atlanta, GA: HowStuffWorks.com. Available from: http://stuffo.howstuffworks.com/animatronic.htm, [Accessed 12th Feb 2006].

Dino Fact File: Allosaurus (1999). [Online], London: BBC. Available from: http://www.abc.net.au/dinosaurs/fact_files/scrub/allosaurus.htm, [Accessed 12th Feb 2006]. NB. While the BBC made the page they have since taken it down. They syndicated the associated program across the world and the Australian Broadcasting Company are still hosting the page being referenced, hence the difference in publisher and source URL.

Exhibits: The EndoVia Surgical Robot (2003) [Online] Boston, MA: Museum of Science. Available from: http://www.mos.org/cst/article/5403/, [Accessed 13th Feb 2006].

Kokoro Dinosaurs (2006). [Online], Woodland Hills, CA: Kokoro Dinosaurs. Available from:
http://www.kokorodinosaurs.com/dinosaurs.html, [Accessed 12th Feb 2006].

Mars Express and Beagle 2 (2nd June 2003). [Online], London: BBC. Available from:
http://www.bbc.co.uk/science/space/exploration/missiontimeline/marsexpress.shtml, [Accessed 12th Feb 2006].

Now Roaming Disney's Animal Kingdom, Lucky the Dinosaur Has Guests in 'Prehysterics' (2004) [Online], [s.n.]. Available from:
http://www.wdisneyw.co.uk/atlucky.html, [Accessed 13th Feb 2006].

Production Notes - Jurassic Park III. (no date) [Online], Broken Arrow, OK: Cinema Review. Available from:
http://www.cinemareview.com/production.asp?prodid=1429, [Accessed 12th Feb 2006].

Roaring T-rex robot unveiled (6th Feb 2001) [Online], London: BBC. Available from:
http://news.bbc.co.uk/2/hi/technology/1155517.stm, [Accessed 13th Feb 2006].

Timeline: Real robots (10th Sept 2001). [Online], London: BBC News. Available from:
http://news.bbc.co.uk/2/hi/in_depth/sci_tech/2001/artificial_intelligence/1531432.stm, [Accessed 12th Feb 2006].

Appendix A – Mathematics used in this project

This section describes the process of calculating the size of gear required to project the tongue from the mouth using only one gear. These equations are based on the equations used for establishing the circumference of a circle.

First we establish the turning distance as a fraction.

$$\frac{200}{360} = \frac{5}{9}$$

This means that a servo can only turn five ninths of a full circle. The servo will be driving a rack and pinion, thus its turning distance governs how far out the tongue will stick. Given that

$$c=\pi d$$

the length of the tongue is given by

$$l=\frac{5\pi d}{9}$$

However, we are trying to establish how big the gear should be. This means that we are looking for the diameter of the circle in question. With rearrangement we can derive

$$9l=5\pi d$$

and therefore,

$$d=\frac{9l}{5\pi}$$

where l is the length of the tongue and d is the diameter of the gear.

The next part describes the process of selecting the transistor and base resistor of the transistor switch used in the circuitry.

The first thing required is the load current. In this project the load is the relay which has a resistance of 100Ohms and a voltage of 12 volts. This gives a load current of

$$I_c = 12/100 = 0.12 = 120mA$$

The transistor requires an h_{FE} rating at least five times the ratio of the collector current to the base current. The output current of the PIC is 10mA and the load current we know to be 120mA. Therefore

$$hFE = 5 * \frac{0.12}{0.01} = 5 * 12 = 60$$

Therefore we know the parameters of the transistor: V_{max}>12V; I_c>120mA; h_{FE}>60. The transistor chosen was a BC184 as that satisfies the criteria. The hFE rating of that transistor is 250 and this is the value used to calculate the rating of the resistor. The rating of the resistor is based on the parameters of the transistor and the equation to establish it is

$$R_B = 0.2 * R_L * h_{FE} = 0.2 * 100 * 250 = 5000 \text{ Ohm}$$

The closest value to this is a 5k1 Ohm resistor so that shall be used as the base resistor, R1 in the circuit diagram above.

Appendix B – Program code for the controller

```
void main(void)
{
	int ic;
	char i0, i1, button, ac=19;

	set_bit(STATUS, RP0);
	TRISA=0x03;			//set to 0b00011
	TRISB=0x00;			//All outputs
	clear_bit(STATUS, RP0);

	output_low_port_a(2);
	output_low_port_a(3);
	output_low_port_a(4);

	output_low_port_b(1);
	output_low_port_b(3);
	output_low_port_b(4); //Unused pins set to output low
	output_low_port_b(5); //to eliminate any spurious current
	output_low_port_b(6);
	output_low_port_b(7);

	while(1)
	{
/*
		create delay 100000=0.1 sec

		while delay not met
			if button break while
		output
*/

		button=0;
		ac=(ac*2)%255;

		for(ic=0; ic<(ac*150); ic++) //total delay= ac*150*ac*100 = 15000*(ac^2)
		{
			while(input_pin_port_a(0)) output_high_port_b(0);
			output_low_port_b(0);
			for(i0=0; i0<ac; i0++)			//0.01sec delay
			{
				for(i1=0; i1<100; i1++);	//100=0.0001 sec
				if(input_pin_port_a(1)==1) button=1; //check 1/10000 sec if button
			}
			if(button==1) break;
		}
		output_high_port_a(3); //Raise outputs of both transistor connection and LED to show
		output_high_port_b(2);
		for(i0=0; i0<100; i0++)			//Delay to allow output to carry
			for(i1=0; i1<150; i1++);
		output_low_port_a(3);
		output_low_port_b(2);			//Lower voltages of output pins
	}
}
```

Program Code to test the timing functions of the controller when it was established that it needed to be tested.

```
void main(void)
{
    char i0,i1,i2,i3,i4,i5,i6,i7;

    set_bit(STATUS, RP0);
    TRISA=0x03;              //set to 0b00011
    TRISB=0x00;              //All outputs
    clear_bit(STATUS, RP0);

    for(i7=0; i7<20; i7++)
    {
        if(i7%2==1) output_high_port_b(7);
        else output_low_port_b(7);
        for(i6=0; i6<20; i6++)
        {
            if(i6%2==1) output_high_port_b(6);
            else output_low_port_b(6);
            for(i5=0; i5<20; i5++)
            {
                if(i5%2==1) output_high_port_b(5);
                else output_low_port_b(5);
                for(i4=0; i4<20; i4++)
                {
                    if(i4%2==1) output_high_port_b(4);
                    else output_low_port_b(4);
                    for(i3=0; i3<20; i3++)
                    {
                        if(i3%2==1) output_high_port_b(3);
                        else output_low_port_b(3);
                        for(i2=0; i2<20; i2++)
                        {
                            if(i2%2==1) output_high_port_b(2);
                            else output_low_port_b(2);
                            for(i1=0; i1<20; i1++)
                            {
                                if(i1%2==1) output_high_port_b(1);
                                else output_low_port_b(1);
                                for(i0=0; i0<20; i0++)
                                {
                                    if(i0%2==1) output_high_port_b(0);
                                    else output_low_port_b(0);
                                }
                            }
                        }
                    }
                }
            }
        }
    }
```

Appendix C – Non Research Issues

There are two main reasons why this project never reached a satisfactory conclusion. Firstly, as there were two people working on different parts of the project, that has twice as much scope for things going wrong. In this instance my partner Gareth ran into certain constraints which, without entering into much personal detail, meant he didn't have as much time to work on the project as was hoped. The design as such meant that it would have been tremendously difficult for one person to construct the main upper section of the model alone so unfortunately the construction of the head as an overall piece had to end there.

However this did not deter me from building something usable and I pressed on with the mechanism for the jaw. Everything was going well until the programming stage. The design of the circuitry had a large oscillator, far larger than the program reasonably required, as recommended by one of the University's electronics experts. As a result, the counter was supposed to run in to some exceptionally high numbers, which it seems was the cause of the problem. This was tested by the second program in Appendix B, which was a series of nested 'for'-loops designed to test the counting abilities of the PIC. This program was intended to flash a series of LEDs in line with the counters so that if one counter was odd then its equivalent LED was lit, and off if it was even. This was run in a nested design with 8 LEDs working concurrently if the program worked correctly. However it was run with two different counting limits, one of 100 and one of 20. When the counters were running to 100 each then the LED light-set only reached the third LED. The counters were then set to running to 20 each, and the light-set reached the fourth LED. This implies that no matter how many counters were being run, the PIC can only count to about 1,000,000 between the lot. The oscillator was being run at 4MHz so in practical terms a count of 1,000,000 is a delay of around 1 second. This was problematic as the design called for delays far longer than that, and with all the other problems that had been suffered during the course of the project a line was drawn under it at this stage.

Other issues were encountered. One minor setback was with the motor on which the cam was placed. A second motor had to be purchased after the one of the wires snapped entering the motor housing. Steps were taken to attempt to prevent this from happening a second time by applying a few layers of sticky tape to the base of the wires where they enter the motor.

Appendix D – List of materials & parts used

Construction Materials:

Roll of Chicken Wire
Small block of polystyrene
Small lengths of wood
Old newspaper
Wallpaper paste
Rip-stop nylon

Electronic Components:

12V power supply
12V / 40RPM motor
7805 voltage regulator
PIC16F84A microcontroller
14-pin PIC cradle
0.33uF capacitor
0.1uF capacitor
4MHz oscillating crystal
2x 0.22pF capacitors
BC337 transistor
SPST relay
2x touch switches
Push button switch
On/Off Power switch
Diode
Resistors:
- 10kΩ
- 4.7kΩ
- 2kΩ
- 3x 330Ω

3x LEDs
Section of stripboard

Tools:

Safety gloves
Safety goggles
Wire cutting pliers
Saw
Soldering iron
Solder
PIC programmer

Appendix E – Quick Reference Tables

Material	Pros	Cons	Used for
Latex	Good aesthetic, can be strong	Can be difficult to use & expensive	Flexible models, or models with realistic skin
Fibreglass	Strong	Difficult and potentially hazardous to use	Large-scale models
Wood	Cheap, strong, fairly easy to use…	…But very difficult to get a decent aesthetic quality	Frames and models not requiring detail
Clay	Fairly cheap, good aesthetic	Brittle	As a base or as very small scale models
Chicken wire/ papier-mâché	Cheap, can achieve a decent aesthetic	Not very strong	Basic, home-made projects

Table A – Material Comparison

Power type	Used in:	Pros/Cons
Electro-mechanic- converting electrical energy into physical movement	Motors, servos, solenoids	Easy to use & implement; Need to be rated for maximum load
Hydro-mechanic- converting fluid into potential energy, to be released into physical motion	Hydraulics, pneumatics	Only need to rate power for the average load; efficient Tricky to implement; need experience to use properly – not for beginners!

Table B – Power Type Reference

Part	Material	Mechanism	Sensors	Actuation
Tongue	Latex	Rack-and-pinion	Limit switch	Servo
Cheeks	Latex & metal pin	Servo & pin	Servo feedback	Servo
Nostrils	Plastic arms/ metal ball	String & ball	Servo feedback	Servo
Jaw	Solid-setting latex	Geared motor & BOE	Binary Optical Encoder	Motor

Table C – Part Actuation Reference

Mechanism	Basis & uses	Pros/Cons
Rack & pinion	A pin within the part stuck within a track to limit movement	Limited domain – can't exceed limits of track Can be noisy as the pin slides and hits the ends
Worm gear	Motor runs a spiral gear to turn output gear	Highly powerful, achieving great rates of torque Slow
Binary Optical Encoder	Disc with certain sections filled and other blank to create a binary pattern	Allows for precise control over rotary actuators Requires a reader, which can be tricky to implement and program for
String & ball	A ball at the end of a length of string from which arms can articulate movement	Allows multiple movements from one actuator Movements can only go in the direction the string is pulling; can be tricky to implement correctly

Table D – Mechanism Reference

Motor Location	Methodology	Pros/Cons
On the pivot	Y-gear & BOE	Powerful & easy to control. BOE can be difficult & costly to create and implement.
Above the pivot	Cam & arms	Cheap and efficient; mechanism hidden while jaw open
Below the pivot	Motor & string	Uses natural forces to achieve – no additional parts Weight balance difficult to achieve perfectly

Table E – Methodology Reference

Part	Constructed design	Updated design
Frame	Chicken wire frame with wooden supports	Unchanged
Mechanism	Cam, arm & spring	Balance over pivot, controlled by motor in rear of the jaw.
PIC	Ran at 4MHz	Changed to run at less than 1kHz
Sound effect	Unimplemented	Use of a sound module for required effect

Table F – Reference of Redesign Alterations