winstanley college

REPORT ON

Remote Rope Deployment System

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SUPPORTED BY

NES ENGINEERING INNOVATION

Engineering Education Scheme England & Scotland EDT

Executive Summary

This report documents the design development process carried out by four students from Winstanley College, with assistance from NES, for a rope positioning system for use in the decommissioning of waste storage silos at the Sellafield site.

Three concepts were identified and evaluated. The solution involved 5 motors, working in conjunction being controlled by a computerised system which is running custom software

The team have successfully identified, designed, modelled, and tested a system that is cost effective, safe and reliable solution that meets the Project brief and the constraints imposed

CONTENTS

1– Introduction to project

1.1 - Background information

Project Background

This report is the culmination of 6 months collaboration between 4 students from Winstanley College and Professional Engineers from Nuclear Engineering Services (NES) Ltd. under the auspices the Engineering Education Scheme. The EES is a programme run by the Engineering Development Trust (EDT) and is designed to develop student’s ‘life skill in the context of the world of work’. A NES Company Profile is in appendix 7.1.1

Background Brief

The Sellafield Site in Cumbria contains a number of concrete silos filled with nuclear waste. This waste is unknown substances, materials and chemicals, that are radioactive and are deemed hazardous to health. The waste cannot be removed by hand as it would endanger people's lives and would be illegal. NES has been contracted to develop a system to decommission the silo plant by safely removing the waste. To achieve this NES have designed are constructing three Silo Emptying Plants (SEP). These will sit on top of the silos and remove the waste through an aperture cut in the silo roof. The SEP will maintain containment by providing shielding whilst in position. The silos measure six metres by six metres by eighteen metres

To protect from radiation the wire rope will operate within a shielded steel box situated directly over the aperture. The winch will be mounted on the roof of the shielding and the rope will pass through a small hole in the roof directly below the winch

The operation of waste removal is by means of lowering a hydraulic bucket through the aperture, which is 1.5m x 1.5m. A rake can be deployed to reach waste at the sides of the silo and bring it into the vicinity of the bucket.

1.2 – Project Brief

As part of this project the team is required to design and model a system that will be capable of positioning the rope to 12 programmable positions.

<u>Constraints</u>

Due to the level of radioactivity:

- No electrical equipment shall be placed inside the shielding box
- Other equipment used must be kept to a minimum.
- The integrity of the shielding box must be maintained.

Due to the hazardous environment the system shall:

- Have little or no maintenance.
- Any maintainable components should be replaced without the need to enter the shielded box

<u>Deliverables</u>

- Three concept schemes
- Concept review and down selection report
- Design drawings
- Working scale model (the drawings should be for the model)

2- Method and Project Plan

2.1 Initial Ideas

The first meeting consisted of a brainstorming session, from this the team decided that 3 options were worthy of further research

Option 1:

This option consists of 4 motors working in tandem, controlled by a computer system, to position a ‘Fixing plate’ in any position over the aperture (similar to the overhead camera system used in sporting events). The wire attached to the bucket will pass through the centre of the fixing plate. The bucket motor will also be driven by the rope-positioning system

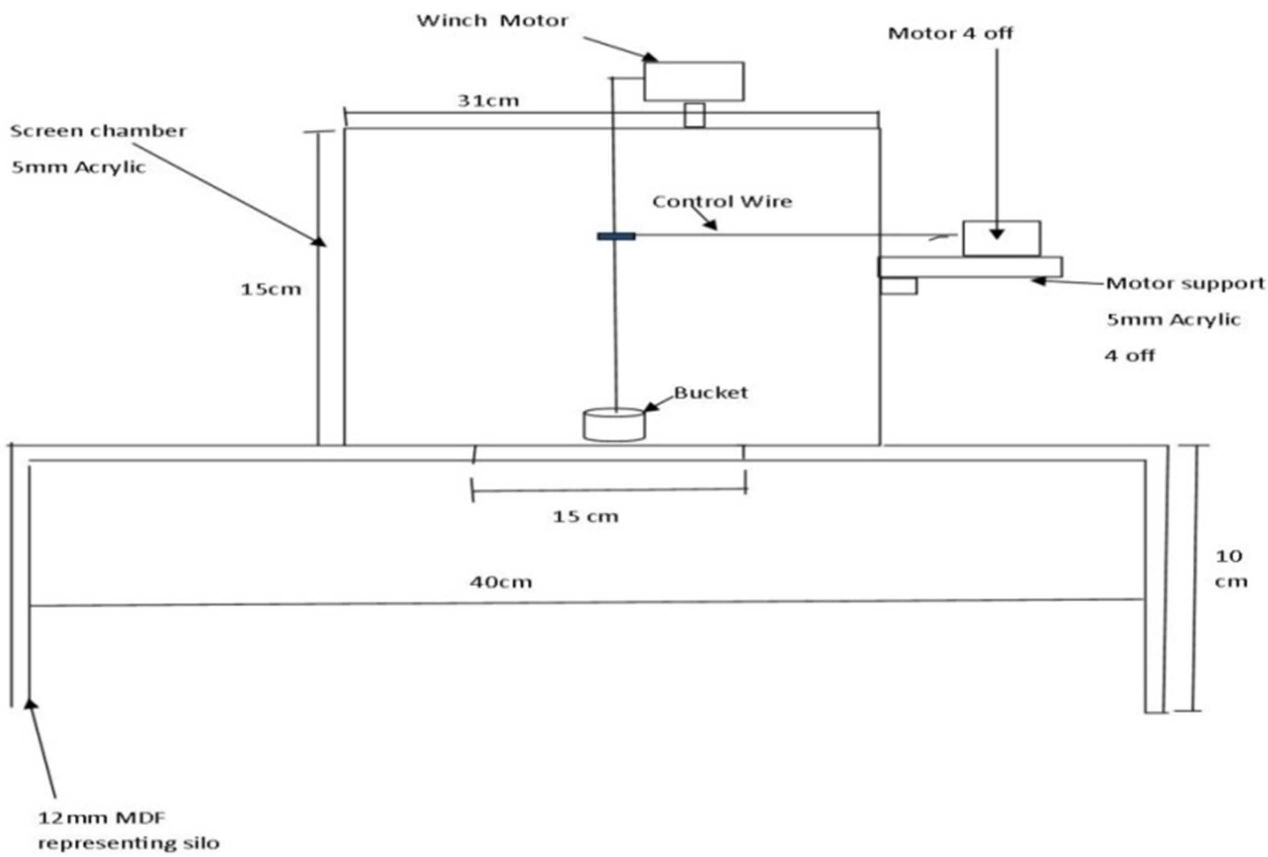


Diagram demonstrating option 1

Advantages:

- A very simple design that is very easy to prove and scale for larger use.
- All components inside of the shielded box are mechanical and do not require any electrical components inside of the shielded box.
- It allows for a near infinite number of positions inside of the shielded box.
- This option keeps the minimum amount of equipment inside the shielded box.
- The only items inside the box are the 4 control wires, the fixing plate and the linkage from the wires to the fixing plate.
- As the equipment required for the solution utilises mostly off the shelf components the cost to implement would be small.

Disadvantages:

- It can be a very slow way to control the rope position.
- It will require a complex control system to work.
- It may be difficult to attain 12 pre programmed positions with this method.

Option 2:

In this option the wire would be manipulated by a bar linkage mechanism similar to a Spirograph or Harmonograph. There would be two bars fixed in each inside corner of the shielded box, which would be able to rotate universally about a joint as pictured below. They would move in unison to position the rope. The 12 programmed positions would be situated along the shape described as the bars rotated.

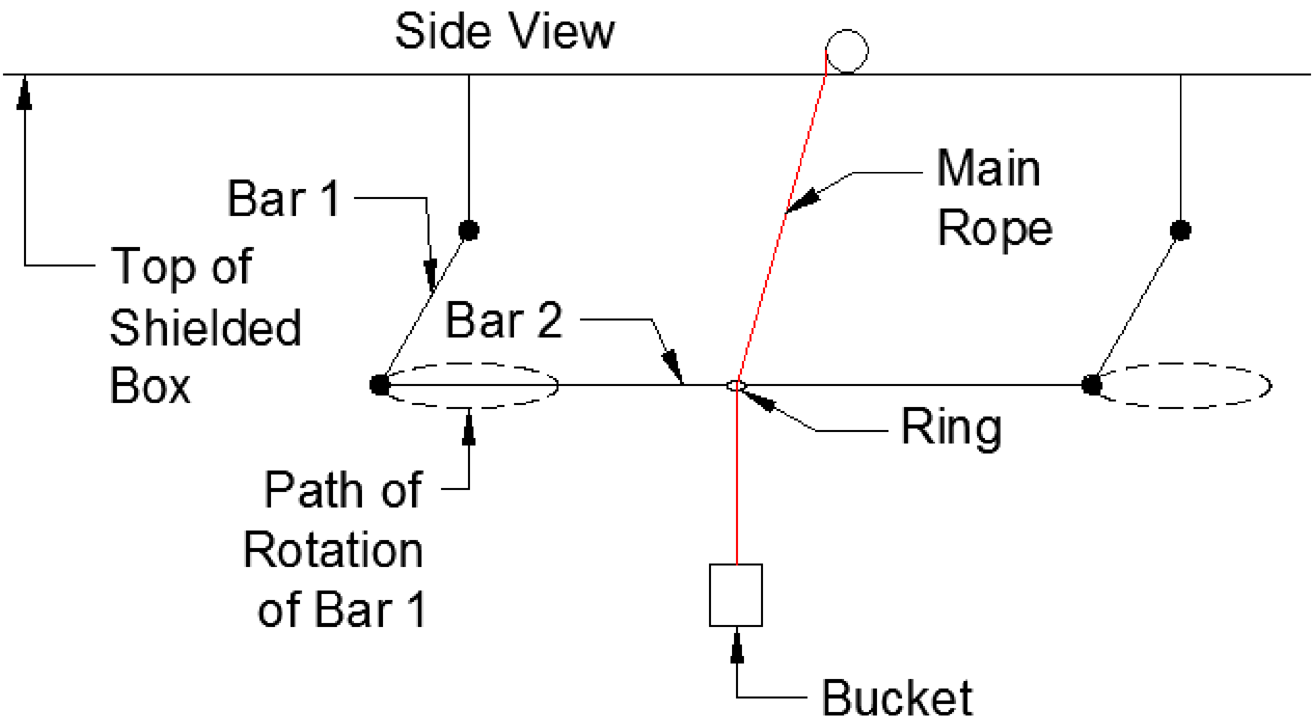


Diagram demonstrating option 2

- The black dots represent joints
- Bar 1 will rotate, which will pull bar 3
- Bar 3 is attached to the ring
- As bar 1 rotates the ring is pulled which pulls the rope
- Bar 2 rotates simultaneously with bar 1, pushing bar 4
- Bar 4 is also attached to the ring
- As bar 2 rotates the ring is pushed which pushes the rope
- Overall effect is that the rope moves towards bar 1 and 3

Advantages:

- Completely mechanical, and so is not subject to electrical malfunctions due to the radioactivity.
- This can achieve 12 pre-programmed positions with the right arm/links configuration.

Disadvantages:

- It will be a large device to install into the shielded box as well as being expensive and difficult to decontaminate or dispose of.
- The amount of equipment inside the shielded box would significantly increase.
- A large amount of the design requires bespoke components so the cost to implement would increase.

Option 3

Hydraulic Arm

This option consists of 2 movable arms linked by a universal joint. The rope would pass through these arms. The positions would be met by rotating the vertical beam and raising or lowering the horizontal beam.

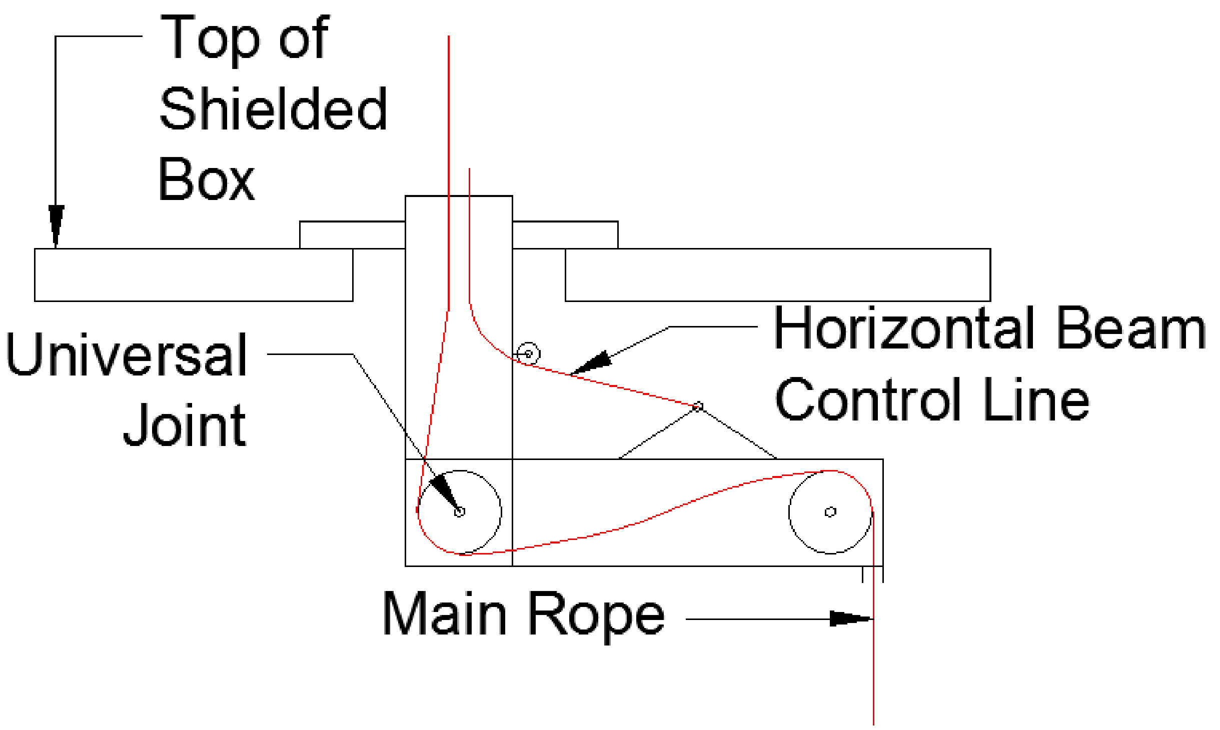


Diagram demonstrating option 3

Advantages:

- This solution allows any position to be reached inside the aperture, and meets the requirement of 12 positions.
- This solution has no electrical components inside the shielding, therefore doesn't compromise the shielding.

Disadvantages:

- This solution places more equipment inside of the shielded box than the other ideas.
- It would need a complicated gear mechanism with a universal joint supporting the weight of the horizontal beam.
- When scaled up it would be prone to a lot of failures due to the complicated mechanical aspects of the solution and hence create a lot of extra waste.
- It requires a very complicated control system, that if failed could cause a large amount of damage to the inside of the shielded box by the control system making the arm do movements that would cause a collision with the box and lead to it being ruptured.
- A large amount of the design requires bespoke components so the cost to implement would increase.

2.2 Decision Matrix

The following chart shows how the final solution was chosen.

Idea	Ability to reach 12 positions	Simplicity	Reliability	Cost effectiveness	Total /40
1	10	9	8	8	35
2	5	4	6	6	21
3	7	6	5	6	24

Scoring System, 10 =Full Compliance   1 = No Compliance

3 - Idea Development

3.1 Proof of preferred concept

After briefing the NES engineers on our three options it was agreed that option 1 was the most viable. The following actions were agreed before the materials were purchased:

1) Prove that by using 4 wires, all positions in an aperture could be reached.
2) Define requirements for the motors
3) Define the requirements for the Control system
4) Design a model that would represent the silo, shielded box and how and where the motors would be fitted, together with materials required

After option one was chosen to be the most feasible the team did a test run using a very basic model. It was made using a square biscuit tin with a hole in the top to simulate the aperture and 4 holes through which the wire were fed. 2 trials were carried out, in one simulation the motors sitting on top of the shielded box the other simulation the motors on the side in the corner. The second trial proved to be the most successful and therefore the planning went forward with this option.

Component Requirements

Motor Requirements

It was decided that the motor needed to meet the following requirements:

1) The motor shall be a Bi-polar Stepper motor with a full step of 1.8 degrees to provide a maximum amount of accuracy, with a repeatability of +/- 5%.
2) The motor shall also be rated at 12v and draw less than a current of 0.5 Amps per motor in order to power the motors using similar voltages to other systems in the design.
3) The motor shall have a holding Torque of greater than 0.2NM so that it can pull and hold a reasonable amount of weight when in use.
4) The motor dimensions should be less than 50mm square and have a drive shaft of 3-7mm and a minimum length of 20mm to allow for rope to be coiled onto the shaft.

H-Bridge Requirements

The H-Bridges need to meet the following requirements:

1) The H bridge shall have a capability of 1 amp output current per driver so that it can drive a motor without the possibility of being destroyed.
2) The application for the H bridge shall include Motor drivers.
3) The H bridge shall be designed for positive supply applications.
4) The supply voltage shall have a range of 4.5v to 36v to allow the ability to control a range of motors.
5) The H bridge shall have a high Impedance diode clamped input to prevent the motor interfering with itself or interfering with other motors.
6) The H bridge shall have a separate input logic supply, have a thermal shutdown capability and have internal ESD protection to prevent any accidental damage to the other parts of the circuit.

Model

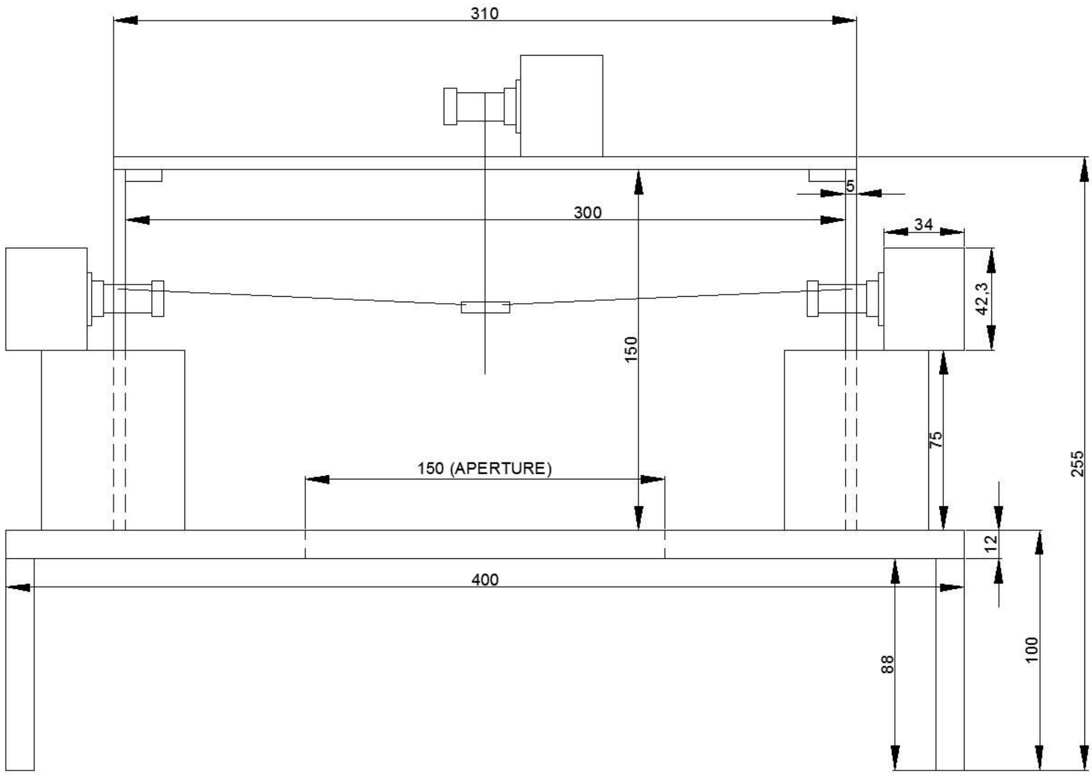


Diagram showing dimensions for the shielded box model

The ‘silo’ is represented by a structure made from 12mm MDF to the dimensions shown above with a 15cm x 15cm hole representing the aperture. The shielded box is represented by 5mm thick Acrylic, cut and glued to the dimension shown. Small holes will be drill through the Acrylic to allow the control wires to pass through. The brackets for the motors will made from three millimetre HIPS plastic. The MDF, the Acrylic and Motors will be purchased, the HIPS are available from college stock.

3.2-Component selection

3.2.1 Control System

The RPS needs a complex control system with the ability to be programmed and have a basic input/output system. 3 options were identified:

i) PLC unit

ii) Raspberry Pi

III) Arduino

Controller	Sufficient Inputs/Outputs	Sufficient Output Power	Pre-built Libraries	Within Budget
Arduino	N	Y	Y	Y
Raspberry PI	N	N	N	Y
PLC	Y	Y	N	N

Recommendation

From the above table it can be shown that the Arduino fulfils the majority of the requirements from the specification, therefore this system will be used.

The Arduino is limited to number of physical outputs on the processor so to expand the number of outputs on the Arduino either a shift register can be used or multiple Arduino can work together to act as one Arduino to control all of the motors. Using Arduino's with shift registers can be very complicated and require a large amount of code to work correctly so it is decided that multiple Arduino's will be used instead as the code for this is the same for nearly all of the chips used.

3.2.2 Motor and H-Bridge options

Motor	Specification met	Price Comparable	Delivery
Hobbytronics SM-42BYG011-25	Y	Y	Y
Robocraft 28BYJ-48	N	Y	N
Nema 17	N	N	N

H Bridge	Specification met	Price Comparable	Delivery
Texas Instruments SN754410	Y	Y	Y
Texas Instruments DRV8834	X	X	Y

Recommendations

Motor – Hobbytronics SM-42BYG011-25

H Bridge- Texas Instruments SN754410

The motor was recommended as it met the specification, was a good price for its specification and would be delivered in time for the workshop.

The H Bridge was recommended as it matched the specification, could be delivered in time and was cheap enough to replace if needed.

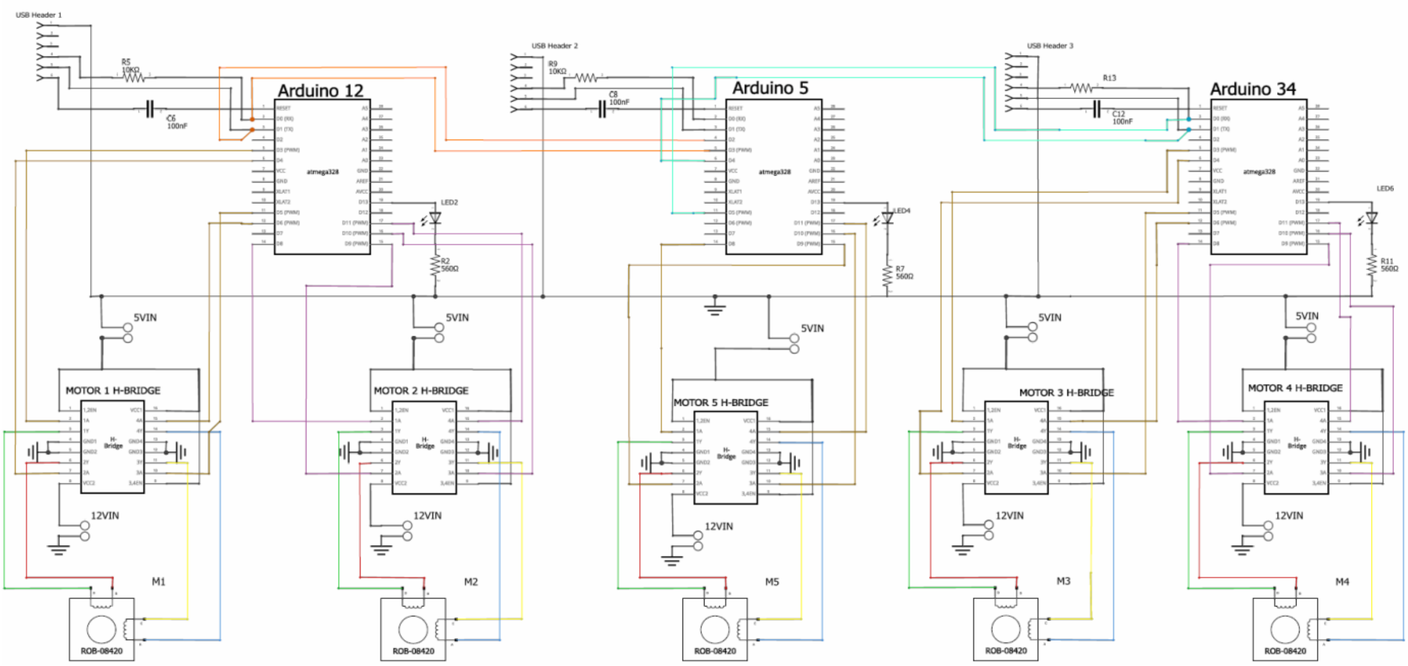
3.3 Circuit design

The solution required a circuit for the control system. The circuit was adapted from an open source design for the ATMEGA328P-PU (Arduino) chips. The circuit required 3 Arduino's, and 5 H-Bridges to power the five motors. A full Electrical Schematic was produced and is attached in appendix 6.5

To simplify the programming, the Arduino's were named based on the motor they powered:

- Left Arduino – Arduino 12 – Powers motors 1 and 2
- Middle Arduino – Arduino 5 – Powers motor 5
- Right Arduino – Arduino 34 – Powers motors 3 and 4

The simplified circuit diagram removing all of the support circuitry for the Arduino (power, clock, etc.) is below.

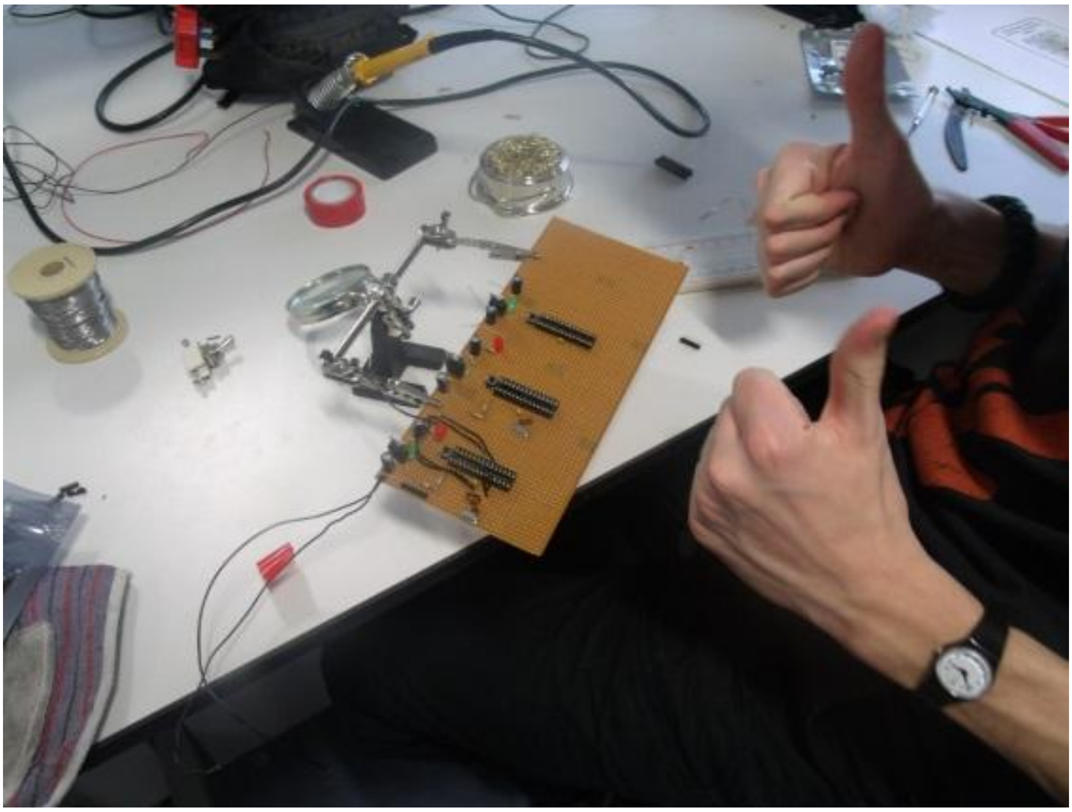


Simplified circuit diagram

There are two communication lines (cyan from Arduino 5 to Arduino 34, orange from Arduino 5 to Arduino 12) that are used to send the number of steps from Arduino 5 to the two slave Arduino's.

There are three separate power rails for the circuit due to the noise created by the ‘stepping’ nature of the motors. Each component that can produce noise has an isolated power supply. This led to the need for a 9V power input for the Arduino's, a 5V power input for the H-Bridge logic, and a 12V power input for the motors. This isolated the Arduino's, which initially produce the oscillating signal to the H-Bridges, from the H-Bridges which output the signal with 12V, and the motors which use the 12V line to work.

The circuit also includes an FTDI header for each Arduino which allows for the uploading of programs, and the necessary serial communication. The circuit was initially designed to work on a breadboard, but it was deemed too temporary. This led to a more permanent circuit to be made on strip board.



3.4 Maths

The control software required an element of mathematics to provide the number of steps each motor needed to rotate, to get to the stated position. The mathematics involved taking the desired position and current position (the position of the main rope) in the forms of x and y coordinates. From this, the mathematical algorithm works out the number of steps each motor needs to turn.

The algorithm created for this followed a simple structure:

- Take the current position and the desired position
- Work out the current length of the rope, using the current position
- Work out the desired length of the rope, using the desired position
- Work out how much longer or shorter the rope needs to be to get to the desired position
- Calculate how many steps each motor needs to turn to get to the desired position

This was complicated by the fact each motor was in a different corner, and because the holding plate needs to be taken into account.

The maths used for this relied on the principle of Pythagoras ($a^2+b^2=c^2$), and right angle triangles.

$RopeLength = \sqrt{(horizontaldistance)^2 + (verticaldistance)^2}$ Horizontal = x, vertical = y.

The rope length is worked out for each motor, and for both the desired position and the current position. This gives two lengths for each motor, the new (desired) length, and the old (current length).

$$Length\ Difference = New\ Length - Old\ Length$$

This length difference calculation gives a value the length of the rope needs to change by to get it to the desired position. This is positive to extend, and negative to retract. This is worked out for each motor.

The number of steps the motor needs to take is show by the following equation:

$Steps = \frac{Length\ Difference}{Length\ Per\ Step}$ The Length per step is a constant and is 0.157 mm per step.

For more information please see the appendix.

Motor Torque Calculations

Note: All measurements are taken as estimates

Mass of weight = 0.2KG

Distance of weight from motor = 0.155M

Assumed max wire deflection angle of 15° from horizontal

For of weight vertically downwards

$w=mg$

$w=0.2*9.81$

$w = 1.962N$

Horizontal Force

$F_x=F\cos Ø$

$F_x= 1.962*\cos(15)$

$F_x= 1.90N$

Torque required on side motors

$T= rF$

$T=1.90 * 0.155$

$T=0.2945 Nm$

$T=0.295 Nm$

Torque required on Top motor

$T=rf$

$T=1.962*0.250$

$T= 0.5Nm$

3.5 Wire and Spooling Mechanism

Requirements	Explanation	Materials that fit requirement	Diameter /mm (lower bound, upper bound)
1. Diameter less than 1.5mm.	The wire needed to enter through a hole in the corners of the box 1.5mm wide.	Electrical wire Dacron Guitar Strings Steel Fishing wire String	(0.250, 1.16) (0.483, 5.04) (0.250, 1.25) (0.0600, 0.260) (0.20320)
2. Flexible.	The wire needed to wind around a device and return to its original state after unravelling.	String Fishing wire Paracord Dacron Electrical wire	
3. Robust.	If the material for the wire frayed, the wires could become tangled or snag.	Electrical wire Dacron Guitar strings Fishing wire	

The wire also had to be capable of withstanding approx. 3N force maximum. This was because the wire would have at least 200g weights vertically hanging from it.

To test that the materials could withstand 3N of weight an experiment was conducted using a table, a pulley and some weights. A clamp was used to hold the wire at one end of a table, and a pulley was positioning at the other end. The wire was then attached to a mass holder and the mass was increased to 300g- the expected maximum in our model to test the strength of the wire.

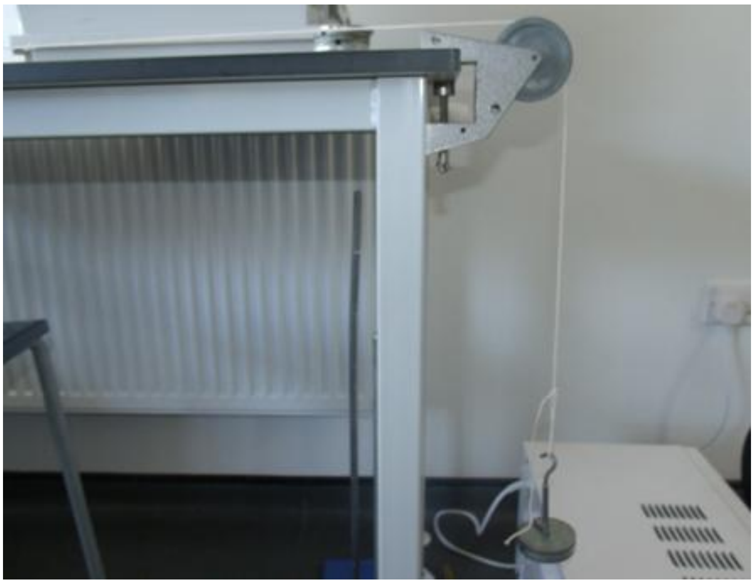


Image showing testing of wire

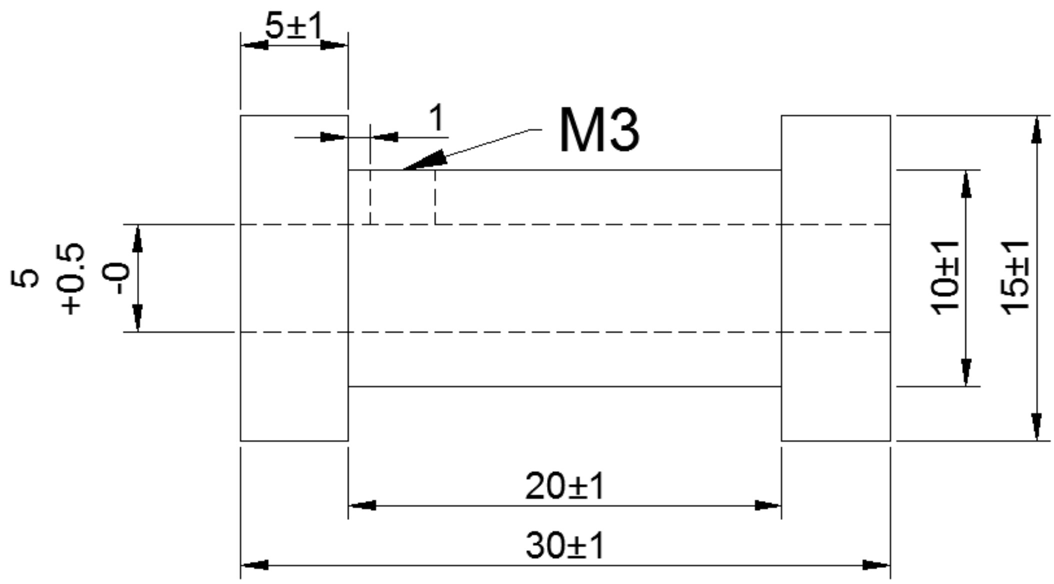
From the results of the experiment, it was concluded that all materials could withstand enough force without breaking. From the above table, the three materials that fit all criteria were electrical wire, Dacron and fishing line. More detailed research was done on these materials to confirm our experiment and quantify their strength.

Material	Cross sectional Area (m^2)	Ultimate tensile strength (MPa)	Breaking Force (N)	Does it fit 3N requirement
Electrical wire	$1.06x10^{-6}$	414	439	Y
Dacron	$1.83x10^{-7}$	55- 75.0	11.9	Y
Fishing line	$5.31x10^{-8}$	754.3	40.1	Y

It was decided to use 1.16mm diameter multi-core electrical wire as it fit all requirements, was the most flexible and was the strongest.

Spooling Mechanism:

Two methods of spooling the wire onto the motor drive shaft were discussed. The first method was by fitting a threaded bush on the drive shaft. The advantage of this is that the diameter of the spooled wire would remain constant. The disadvantage is that the angle at which the wire entered the shielded box would vary with the pitch of the thread. Method 2 was a plain 'bobbin' spindle fitting over the drive shaft and fastened by a grub screw. This would ensure that the angle of the wire would remain constant. The disadvantage is that if the wire wound over itself the diameter of the spindle would change. Thus the amount of linear movement per step, would vary. Further detailed calculations show that this effect would be minimal so it was decided to proceed with this option.



Sketch showing dimensions of spool

4 Problem Solution and Evaluation

4.1 - Workshop

A Gantt chart showing the specific activities planned for the Liverpool workshop was drawn up a copy is in appendix 8.3

4.2 - Assembly of model

The Silo and shielded box were assembled before the Liverpool workshop. This was accomplished using the college facilities.

During the construction of the model the team recognised that the original design for holding the motor was too unstable to be glued into place on top of the box. However it was discovered that when it was running the vibrations caused by the spindle rotating made the motor move out of position and would stop a smooth running of the motor making the RRPS jumpy. To reduce the amount of vibration caused by the motor the team decided to hold the motors in plastic brackets to reduce the vibrations. Five of plastic brackets were each made from 80mm x 50mm x 3mm HIPS. These were bent under a heat source and then drilled to take the motor location screws and fixing screws.

The motor location blocks and brackets were then assembled ensuring correct alignment with the corner of the shielded box by measuring the offsets of the motors from the edges of the wooden blocks. The 4 holes could then be drilled ensuring the correct height was maintained.

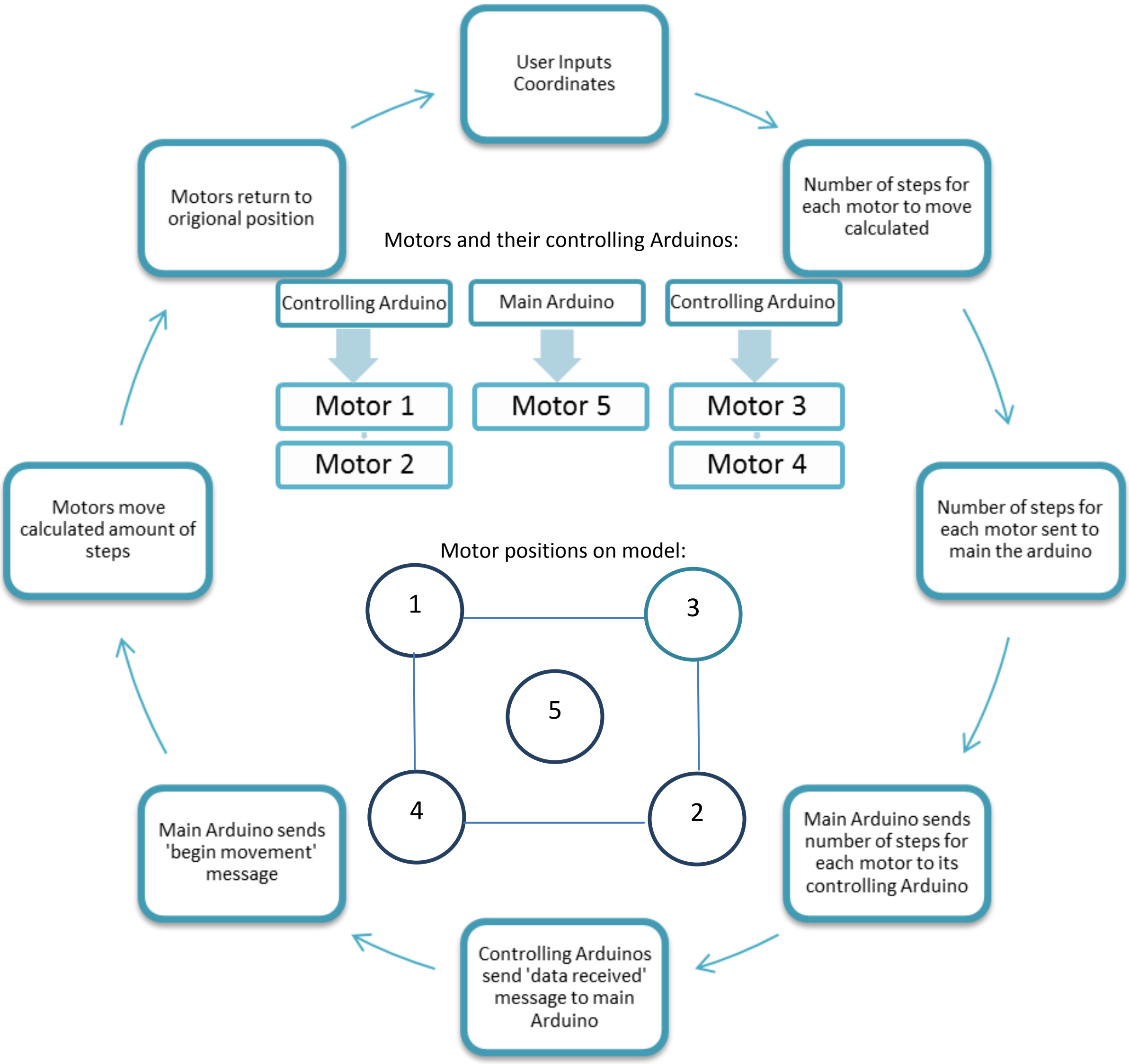
4.3 - Control System

To enable the testing of the solution, it was necessary to build a small test circuit. A simple breadboard circuit consisting of two H-bridges and an Arduino Uno was built. Two motors could be tested at a time. The Arduino Uno was programmed with a simple program that would turn motor 1 a full revolution clockwise, and motor 2 a full revolution anticlockwise. This would test the ability of one Arduino driving two motors through two H-bridges. Testing all 5 motors proved that a single Arduino can run two motors in opposite corners with no delay confirming our proposed solution was viable. It also confirmed all five motors were working and could support a mass of 100g, which was a requirement for the model.

The complete control system (H bridge and Arduino's) could then be built with a higher degree of confidence. The completed system was assembled on strip board and tested. Once this was confirmed to be correct the chips were fitted and a simple program uploaded to them. This program lit a red LED to prove the Arduino was working as predicted. A second program was then loaded that confirmed all motors worked in conjunction correctly. This was successfully demonstrated and was proof the concept was viable.

4.4 - Programming

Whilst the mechanical and electrical aspects were being assembled the programming code needed to be defined. To help with this, a flow chart showing the interactions was drawn.



Pseudo code diagram

Outline

Two programs were needed to achieve the method shown in the flow chart.

1. Calculates how many steps the motors needed to move based on user inputted coordinates.
2. Uses the Arduino to control the movement of the motors.

The user's coordinates would be based on a coordinate system where motor 4 is at (0,0), and motor three is at (300,300). The number of steps for each motor to move would be sent to the main Arduino in a specific order, and then the correct data for each motor would be sent to the Arduino that controls it.

Research
Research was conducted on inter-Arduino communication by sourcing the information from the Arduino site. The language used was the Arduino programming language, and the Arduino development environment was used to write the programs.
The two libraries available for communication between Arduino's were the wire library and the software serial library. After research into existing programs, the wire library could not be used to send messages simultaneously from the main Arduino to the other Arduino's and so the software serial library was used.

Motor Synchronicity
The motors had to start moving at the same time so that the wire didn't slack and wasn't being pulled in the wrong direction. The program for the Arduino's that controlled the motors couldn't be written linearly with one instruction after another as this would cause one motor to start moving once the other had finished. The method listed here was used to overcome this problem.

1. Each motor was moved one step at a time
2. Each motor moved the number of steps they had in common with each other
3. If one motor required more steps it was then moved its remaining steps

4.5 - Summary of Workshop

Although the majority of the planned work was completed, there were some problems encountered with the building of the circuit board which meant that the team had to complete the work in college. This was successfully completed within 4 weeks. With the help of the undergraduates, technicians and tutors from Liverpool the team found their support was invaluable and has given the team a real insight into University life.

5 - Future Developments and Implementation

Future Developments

For the demonstration model it succeeded in being a proof of concept model; Showing that the idea of a RPS would work and be a possible solution for NES. However, If the group had more time to work on the project, possible improvements could include; making a custom circuit board for the circuit; and maybe also add Better wire to the box, and develop the programs more, by providing them with a GUI, A positive feedback system and more precise motors and controllers.

Implementation

The model proved that the concept of using 5 motors driven by a control system was valid.

To implement this as full scale solution, the following would need to be taken into consideration

1. The proposed solution used stepper motors to move the ropes and the bucket around. Currently, there are no stepper motors with sufficient power/torque output or accuracy (in terms of steps per revolution) that would be required for this solution. It is therefore recommended that NES use conventional DC motors and build custom gearing system that can finely control the output and hence the position of the main rope. This system would also have a feedback system that the solution proposed lacks, allowing the operator to know for certain the rope is in the correct place.

2. Wire with the correct properties in terms of flexibility and breaking strain needs to be researched

3. A ROM cost for this type of installation, not including labour costs, is estimated between £1 million and £10 million based off industry information

6 - Conclusions

Over the course of the EES project the team has had to learn many skills for the successful completion of the project; whether this be learning how to program or circuit design to problem solving and leadership skills. The team has also gained a larger skill set in the engineering field and have learnt new things that without the EES Scheme would not be known. Prior to the project the team did not know each other, but through the scheme they have developed an ability to work well together. The project has greatly improved the group's communication skills and team working ability.

The solution was a success, as it overcame these constraints given in the brief.

- No electrical equipment should be placed inside the shielding box due to the level of radioactivity and other equipment must be kept to a minimum
- The integrity of the shielding box must be maintained
- The system requires little or no maintenance due to the hazardous environment.
- Any maintainable components should be replaced without the need to enter the shielded box

7 - Appendices

7.1 - Company Profile

Nuclear Engineering Services (NES) specialise in the design, manufacture, assembly, test, installation and commissioning of bespoke solutions for the nuclear decommissioning, defence, and nuclear new build markets.

NES has over 60 years nuclear experience, with company origins dating back to John Thompson and the supply of the first nuclear reactor housing to Dounreay.

NES has supplied an extensive range of equipment and solutions to most UK nuclear power stations, including fuel route, remote handling, inspection equipment, encapsulation, waste handling solutions, glove boxes, shielded containments, and reprocessing equipment.

Engineering department capabilities include concept through to detail design, design substantiation, safety case support, peer reviews and feasibility studies, site surveys and reports. Engineering resources are split across 2 NES sites, Wolverhampton – Head office, and Risley – Centre of Engineering Excellence.

Manufacturing, assembly and test facilities, are located at both Wolverhampton, and NES' new North West Division in Beckermet, the closet facility of its type to the Sellafield site. Both facilities contain high bay test towers up to 30m, and 6m deep test pit facilities.

NES manage projects through Integrated Project Teams (IPT) engaged in engineering, manufacturing, assembly and testing, driving a disciplined and structured approach to planning and project management, the key to successful contract performance.

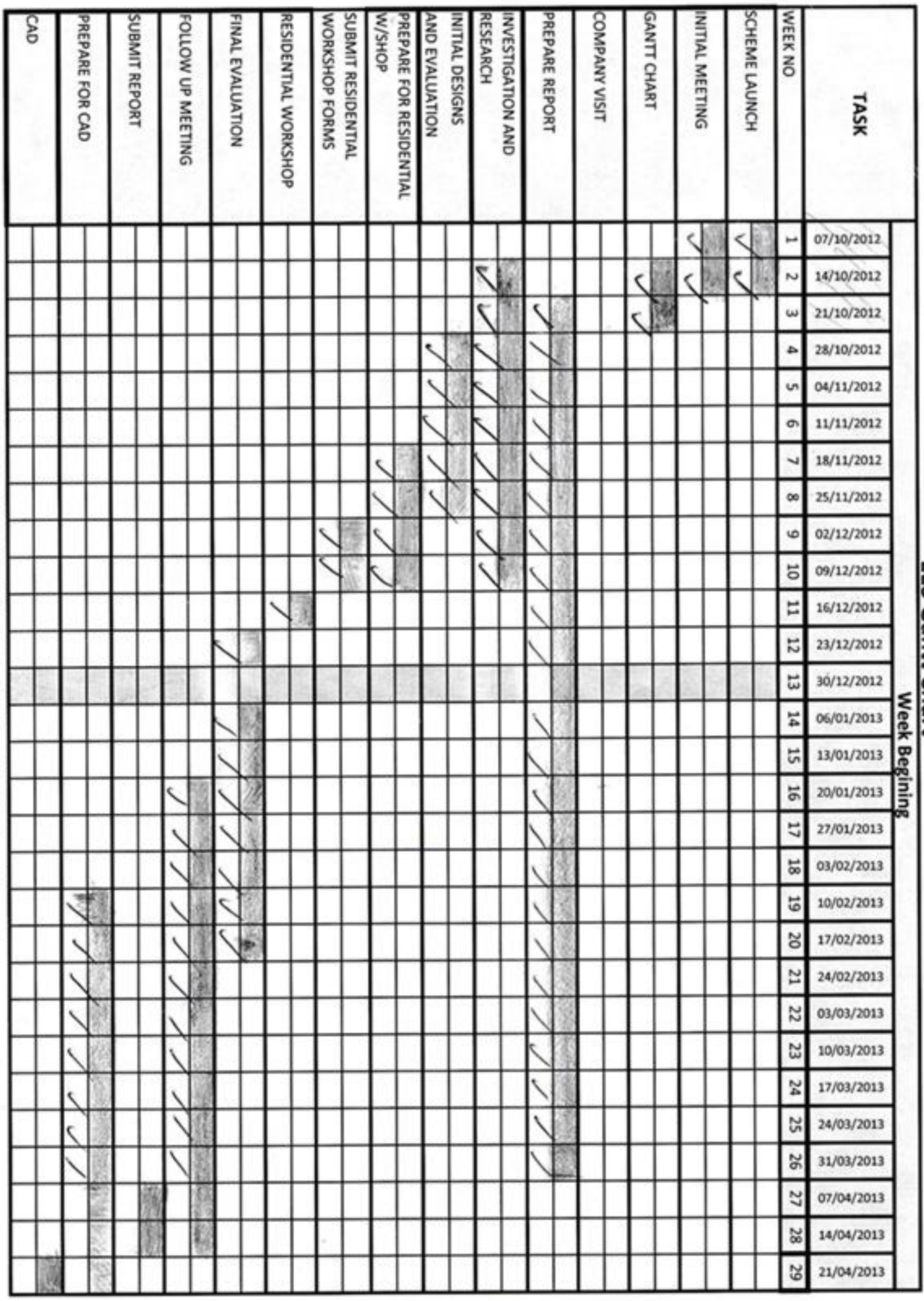
NES also retain Ultra High Pressure (UHP) water jet technology capabilities including UHP cleaning and decontamination units that can be fixed to a manipulator for remote access in hazardous environments.

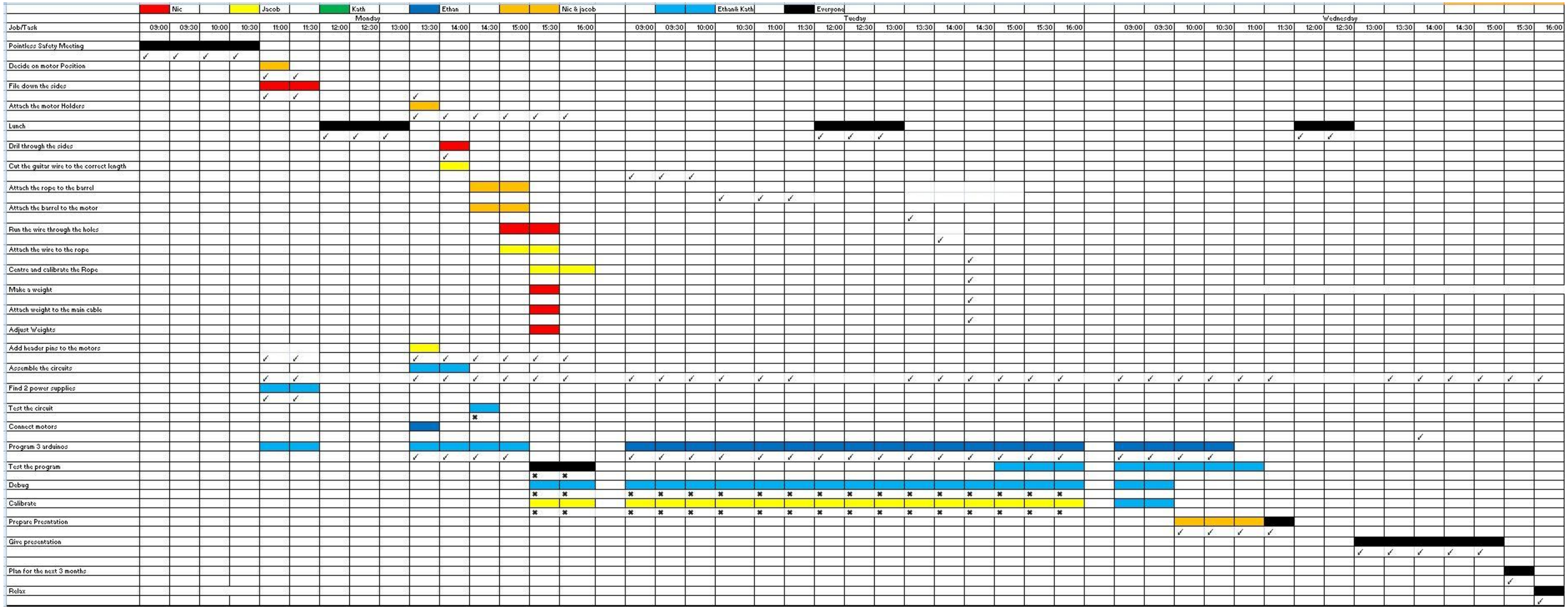
7.2 - Our team

Ethan Spall - Team Leader/ Lead programmer
Jacob Kay - Electronics Engineer
Kathryn McGregor - Arduino Programmer
Nic Gaskell - Model Engineer

7.3 - Gantt chart

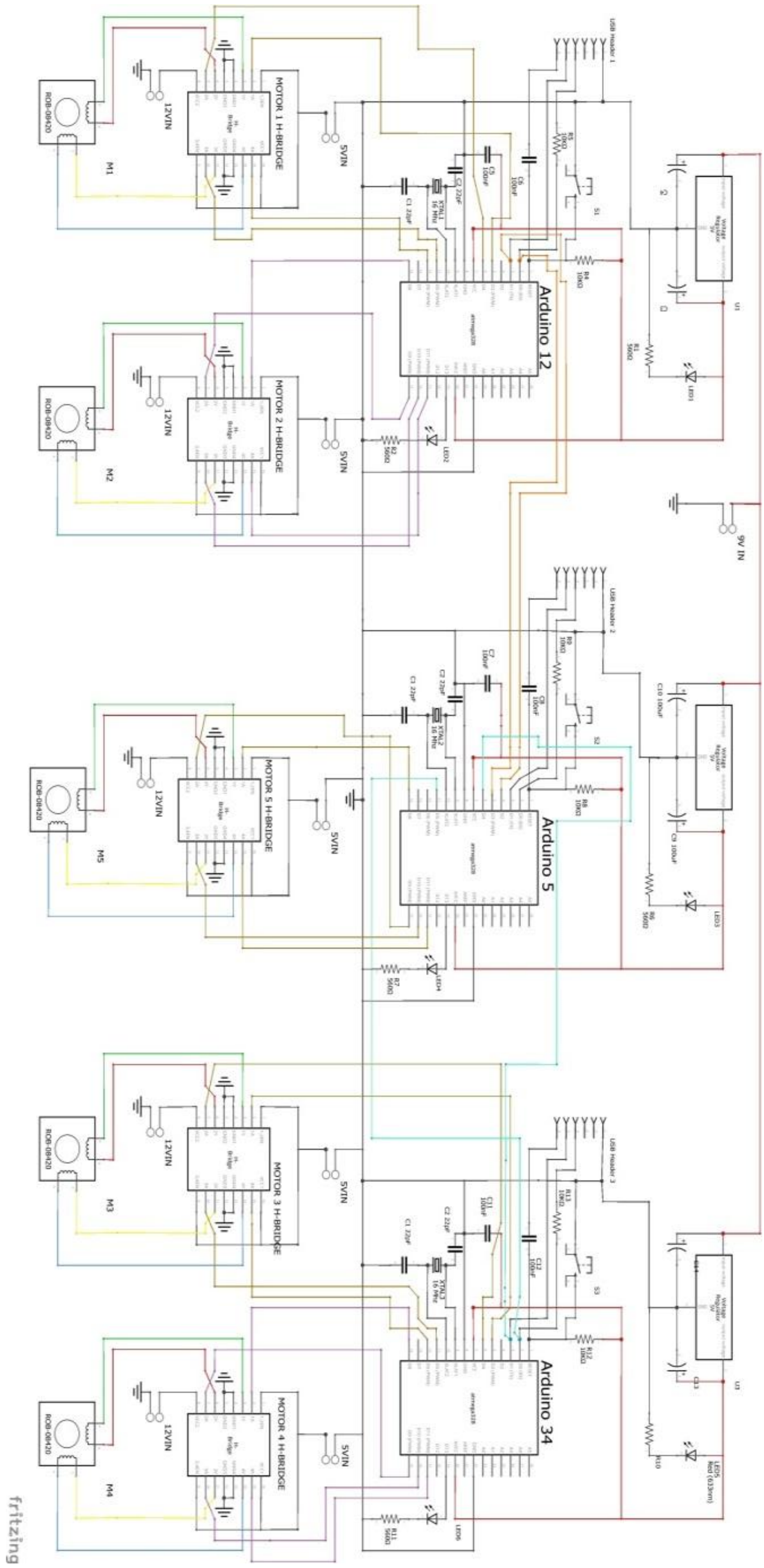
For the duration of the project we used the below Gantt chart to plan out what we needed to do over the course of the project. It is clear from the Gantt chart that we were able to follow what we had planned out.



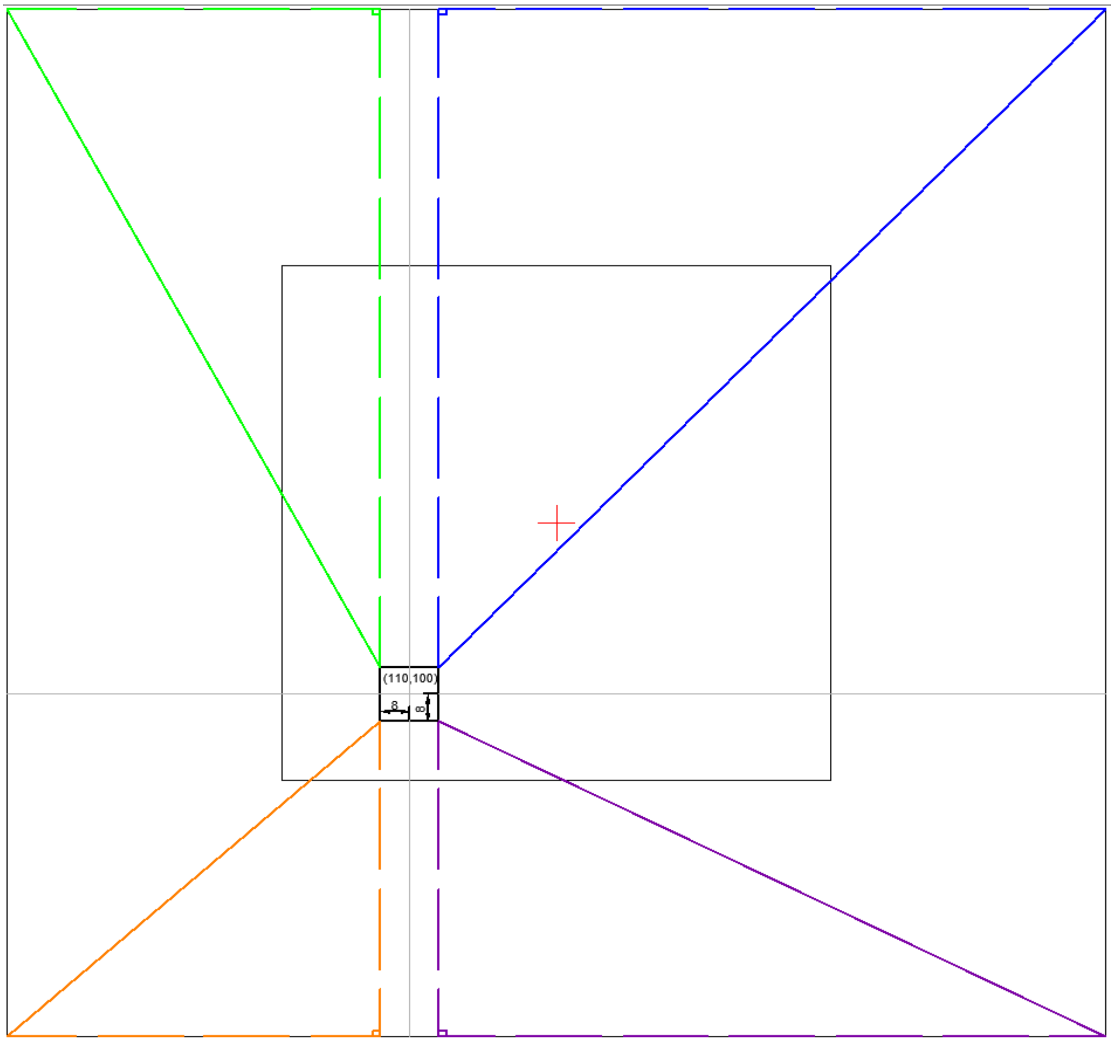

Nic
Jacob
Kath
Ethan
Nic & jacob
Ethan& Kath
Everyone
Monday
Tueday
Wednesday
Job/Task
09:00
09:30
10:00
10:30
11:00
11:30
12:00
12:30
13:00
13:30
14:00
14:30
15:00
15:30
16:00
Pointless Safety Meeting
Decide on motor Position
File down the sides
Attach the motor Holders
Lunch
Dril through the sides
Cut the guitar wire to the correct length
Attach the rope to the barrel
Attach the barrel to the motor
Run the wire through the holes
Attach the wire to the rope
Centre and calibrate the Rope
Make a weight
Attach weight to the main cable
Adjust Weights
Add header pins to the motors
Assemble the circuits
Find 2 power supplies
Test the circuit
Connect motors
Program 3 arduinos
Test the program
Debug
Calibrate
Prepare Presentation
Give presentation
Plan for the next 3 months
Relax

7.4 - Calculations, Tables, Figures

7.4.1 Circuit Diagram



7.4.2 - Maths



The diagram above illustrates how the maths is applied to the problem. Each motor is colour coded, M1 Orange, M2 Blue, M3 Green, M4 Purple. The solid, coloured lines show the rope going from each motor to the holding plate (the small black square), the dashed lines show the horizontal and vertical distances for each of the ropes.

The maths used for this relied on the principle of Pythagoras ($a^2+b^2=c^2$), and right angle triangles.

$$Rope\ Length = \sqrt{(horizontal\ distance)^2 + (vertical\ distance)^2}$$

However it is not as simple as just using the x and y coordinates because each motor is in a different corner and the holding plate means the ropes don't reach the central rope.

The diagram above shows the rope being positioned in (110,100), and the holding plate is 16mm by 16mm meaning 8mm from main rope to each corner rope.

For example, the horizontal distance of Motor 2's rope is given by (300- (x +8)) =

(300 – (110+8) = 300- 118 =182mm. The vertical distance is given by (300-(y+8) = (300-(100+8)) = 300-108=192mm. This means the length of the rope is = $\sqrt{(182)^2 + (192)^2} = 264.55mm$. This can be combined with another position to work out another length, and hence the length difference which means the number of steps can be worked out.

Motor 5 presented a challenge because it is above the centre of the aperture, and the rope enters 90mm above the plane of the holding plate. This meant it required two iterations of the Pythagoras equation. The first was used to work out distance from (150,150) (centre of the shielded box) to the position, and the second one is used to work out the length of the rope from the rope entry point to the position. The second iteration uses the vertical distance as 90mm, and the horizontal distance as the value obtained from the first iteration. This gives the rope length from the entry point to the holding plate. The length the operator wants the rope to be, below the holding plate is then added to this since it will be a vertical rope at that point. This then is used twice, a length difference worked out, and the steps calculated.

Working out the maximum length of rope needed was easy, and required a simple calculation using the rope length equation. This was done with the possibility of expanding the 150mm by 150mm aperture to a 200mm by 200mm aperture. This meant the furthest position from the origin, and hence the longest length for motor 1, was (250,250).

$$Maximum\ Rope\ Length = \sqrt{(250)^2 + (250)^2} = 353.55\ mm$$

This was rounded up to 400mm for the extra rope needed outside the box and to allow it to be attached to the holding plate.

The rope drum has a 10mm diameter where the rope is put on. This allows for the length of a turn of rope to be worked out and hence the number of turns of rope needed on the drum.

$$One\ Turn\ of\ Rope = \pi d = 10\pi = 31.416\ mm$$

$$Number\ of\ Turns\ On\ Drum = \frac{Length\ of\ Rope\ Needed}{Length\ per\ turn} = \frac{400}{31.416} = 12.7\ turns$$

$$Length\ of\ Drum = Number\ of\ Turns * Diameter\ of\ rope = 12.7 * 1.6 = 20.32mm$$

The length of the drum was rounded down to 20 mm as part of the rope would always be inside the shielded box.

7.5 - Minutes of meetings

Instead of having one person take notes for the entire meetings, all of the meetings with the engineers were recorded so that the group can look back at the meetings and all that was said and it also allowed the group to have clarification on the decisions made. Therefore the minutes of the meetings are not available to put on the report.

7.6 - Summary of key communications

The first meeting that occurred with NES involved the discussion of the brief. Within this meeting background to the problem at Sellafield was outlined and the limitations and requirements of our project were discussed. This lead to brainstorming potential solutions.
Another important meeting was to decide upon the final idea. After proposing the 3 concept ideas to the engineers and discussing their strengths and limitations, a design matrix was made to compare the ideas. This involved going through our sketches and comparing them to the requirements of the brief. Using this allowed direct comparison between them to decide which idea was best.
Once the final idea was chosen, finalisation of the dimensions of the model was needed. This involved discussing with the engineers the exact method of modelling our solution, and the relative sizes of the component parts.
Research into what materials and equipment were to be used for the model involved a meeting in which the requirements of the motors and control systems were defined. After thorough analysis of products that satisfied these requirements, emails were sent to and from NES explaining the reasoning behind which products were best. This concluded in the right products being bought which the team and NES had both accepted and agreed upon.

7.7 - Company Visit

NES Visit to Head Office in Wolverhampton 6TH February 2014

Background

NES has 3 sites in the UK, the Head Office at Wolverhampton, and Engineering sites at Risley, and Beckermet. We were invited to visit the Site at Wolverhampton on the 6th of February. The Head office sits has the following capabilities

Detail Design
Manufacture
Assembly, Test and Commissioning
Training
Procurement and Project Management

Immediately after arrival and signing in to the site we were given a health and Safety briefing and issued with the appropriate PPE which included a Hard Hat, Safety Shoes, Goggles and Ear protection.
In the morning we were shown round the Manufacturing Machine shop, which

included 4 and 5 axis machines, and 3 axis horizontal Milling Machines. These machines were mainly used for small batch work.
From the machine shop we were shown the Ultra High Pressure water jet which is used for profile cutting using abrasive in an Ultra High Pressure jet of water.
After Lunch we were shown round the main project on site the Silo Emptying Plants (SEP)
These were of particular interest as our project was part of this facility, the rope deployment system being the first stage of the emptying (FSD – FIRST STAGE DEPLOYMENT). The team was amazed at the complexity of the embedded engineering and the Project Controls and management involved. We were able to look closely at were our project would fit into the overall SEP concept.

7.8 - References

For the project the following resources of information were used:

http://arduino.cc/

Stepper motors:
http://robocraft.ru/files/datasheet/28BYJ-48.pdf
http://arduino-info.wikispaces.com/SmallSteppers

http://www.hobbytronics.co.uk/motor-control/stepper-motors/stepper-motor
http://www.hobbytronics.co.uk/tutorials-code/arduino-tutorials/stepper-motor-sn754410

http://arduino.cc/en/uploads/Tutorial/Unipolar_sch.jpeg
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Stepper motor chips:
http://www.hobbytronics.co.uk/h-bridge-driver-sn754410
http://www.hobbytronics.co.uk/ftdi-basic

Arduino:
http://www.pighixxx.com/pgdev/Temp/ARDUINO_V2.png
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http://forum.arduino.cc/index.php/topic,108697.0.html
https://digistump.com/board/index.php?topic=1051.0

http://oomlout.co.uk/collections/arduino/products/arduino-component-bundle-arcb

7.9 - Glossary

GUI - Graphical User interface
Handshaking - An exchange of signals used to establish communication between the devices wishing to communicate
NES - Nuclear Engineering Services
PLC - Programmable Logic controller
RPS - Rope Positioning system
RPI - Raspberry pi
RRPS - Remote Rope Positioning system
SEP - Silo Emptying Plant
Electrical Noise - A random fluctuation in an electrical signal, a characteristic of all electronic circuits. Noise generated by electronic devices varies greatly.
FTDI - Future Technology devices international
USB - Universal Serial Bus, an external bus standard that supports data transfer rates of 12 Mbps.
Decoupling capacitor - A capacitor used to decouple one part of an electrical network from another.
Ground - Electrical connection to the Earth.
RX/TX - Receive data/ Transmit data
HIPS – High Impact Polystyrene
ROM - Rough Order of Magnitude

7.10 - Acknowledgements:

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