ENS3105/ENS6132: Mechanical Design and Development

Major Assignment Design Report

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Group 14

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Introduction

Warman Competition

The Warman Design and Build Competition 2022 is based on the design and building of the device that can transport a package from the warehouse stating at the start zone delivering to any of deposit zone and finally returning to the start zone. There are four deposit spot A, B, C and D smaller the zone area higher the points. The system must be autonomous and should not touch the chasm zone at any point of device run. Zone. The system may contact any surfaces within the boundaries of the Start Zone, including the rope and maximum time for all the action i.e. collection, delivery and return is 120 second.

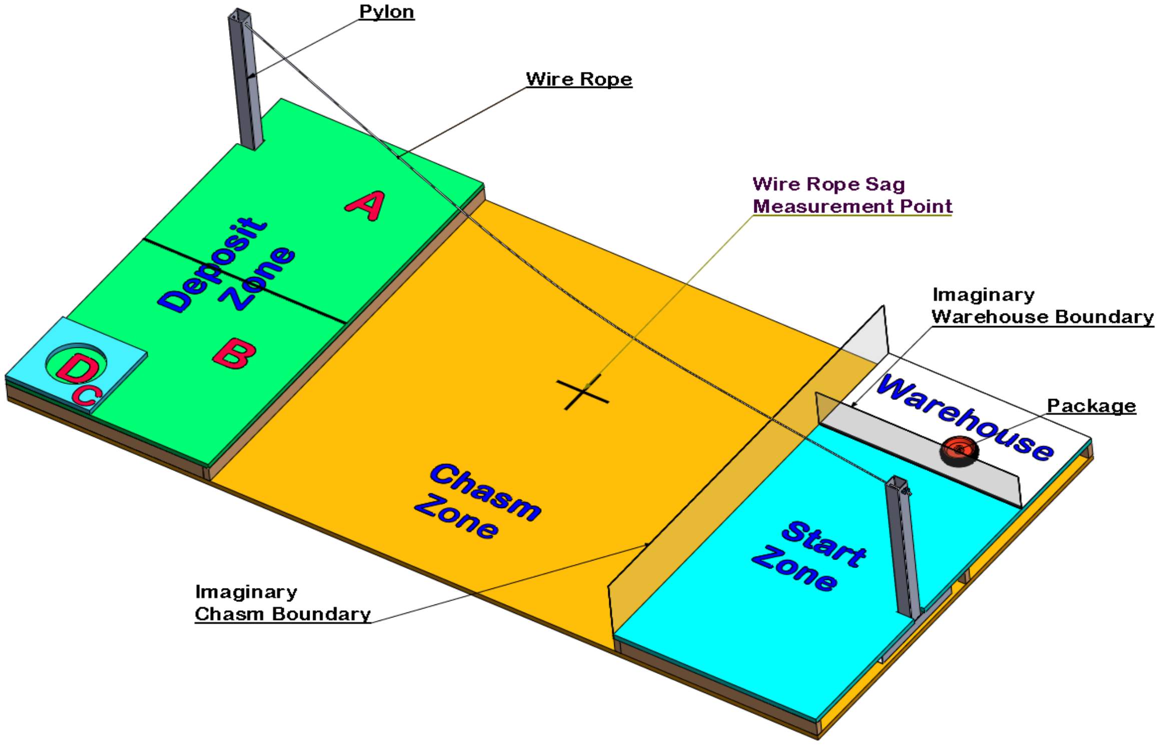


Figure 1: Schematic view of the Competition Track showing the Start Zone, the Warehouse with the package, the wire rope across the Chasm Zone and the Deposit Zone. The boundary planes are shown for clarity.

Design specification

Problem definition

Warman Design and Build Competition 2022 need to build such that the system can collect, deliver and return to initial position. This report includes some of our Concept design, PDS of system analysis, Manufacturing Process, Cost Analysis, various stress calculation and safety factor also the CAD design of our device.

Constrains

- The system must be autonomous and start with a single action.
- The system has to be set up within a start zone, from where the system goes to the warehouse area, collects the package, delivers it to the delivery zones and comes back to the start zone.
- The system weight should not exceed 6kg, and the whole process should be done in 120 seconds.
- The system must be safe for the operating conditions. It should have fuses when electrical components are installed.
- After the device has been set up in the start zone, its height should not exceed 600mm.
- The system must not touch chasm zone any time of device run.
- The system must assemble within 2 minutes in competition at start zone.

Research and Brain storming

Individual research was done by each individual for concept design considering the constrains of the competition. Multiple ideas and design were presented each with different mechanism and task to achieve. Various manufacturing techniques and material of device were chosen for device. Reference from previous competition and textbook as well as lecture notes were considered to form a PDS (Product Design Specification) and Calculations.

Product Design Specification (PDS)

PDS of device includes the basis of the design that need to considered for final prototype of design for effective design. This help to build the layout of design that we need to consider in our concept design. PDS also fixes the criteria that designer need consider for concept that may be a final design.

Criteria

- Accuracy and reliability: The device should be able to pick up the package from the warehouse and deliver it to different delivery zones (A, B, C or D). It should perform the task in 120 seconds.
- Safety: The system should be safe and comply with all the competition rules and requirements. Fuses should be used with electrical components.
- Patent and product data: There should be no use of logos or Mindstorms. Readily available components must fabricate the system or modify off-the-shelf components.

- Ergonomics: The system should work with a single action that should not produce motion or energy. The system should not be touched or controlled during the run by anyone. It must not damage the surface or track.
- Material and weight: The material used should be readily available. It should be lightweight and robust so that weight should not exceed 6 kg. There would be no use of materials that damage the track.
- Environmental conditions: The system should work in temperatures (10-55C) and atmospheric pressure conditions. It should also work in windy conditions and a range of 0-31mph.
- Cost: Cost less as possible/ cost effective.
- Developing Time: should be less than 6 weeks.

Concept Design

Various concept was presented by each individual by research and course study considering the given criteria and constrains. Each concept had different mechanism and design. Few of the concept are presented bellow and their working and limitations.

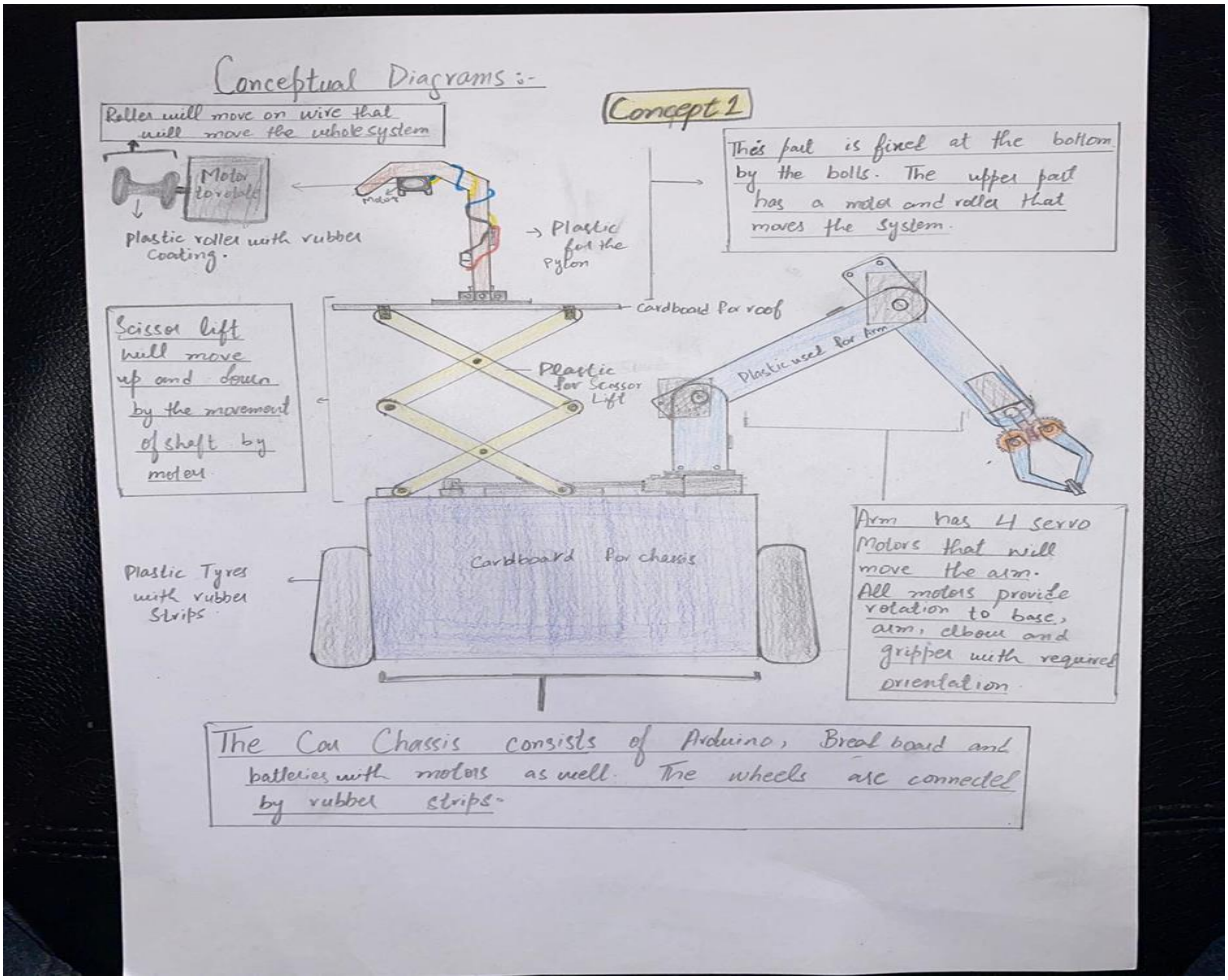


Figure 2: concept 1

Concept 1 works as basic car chassis design which all the mechanism is mounted on the top of chassis. This design got robotic arm with 3 servo motors which is attached to the chassis, and a scissor mechanism to lift the device on the wire. At the top of scissor, it has a roller with DC motor that drives on the wire.

Limitations

Concept 1 has one major problem i.e. scissor mechanism which is not suitable to lift the device rigidly causing dropping is package. And use to too many motors that is leading to use of large Arduino costing more for the project.

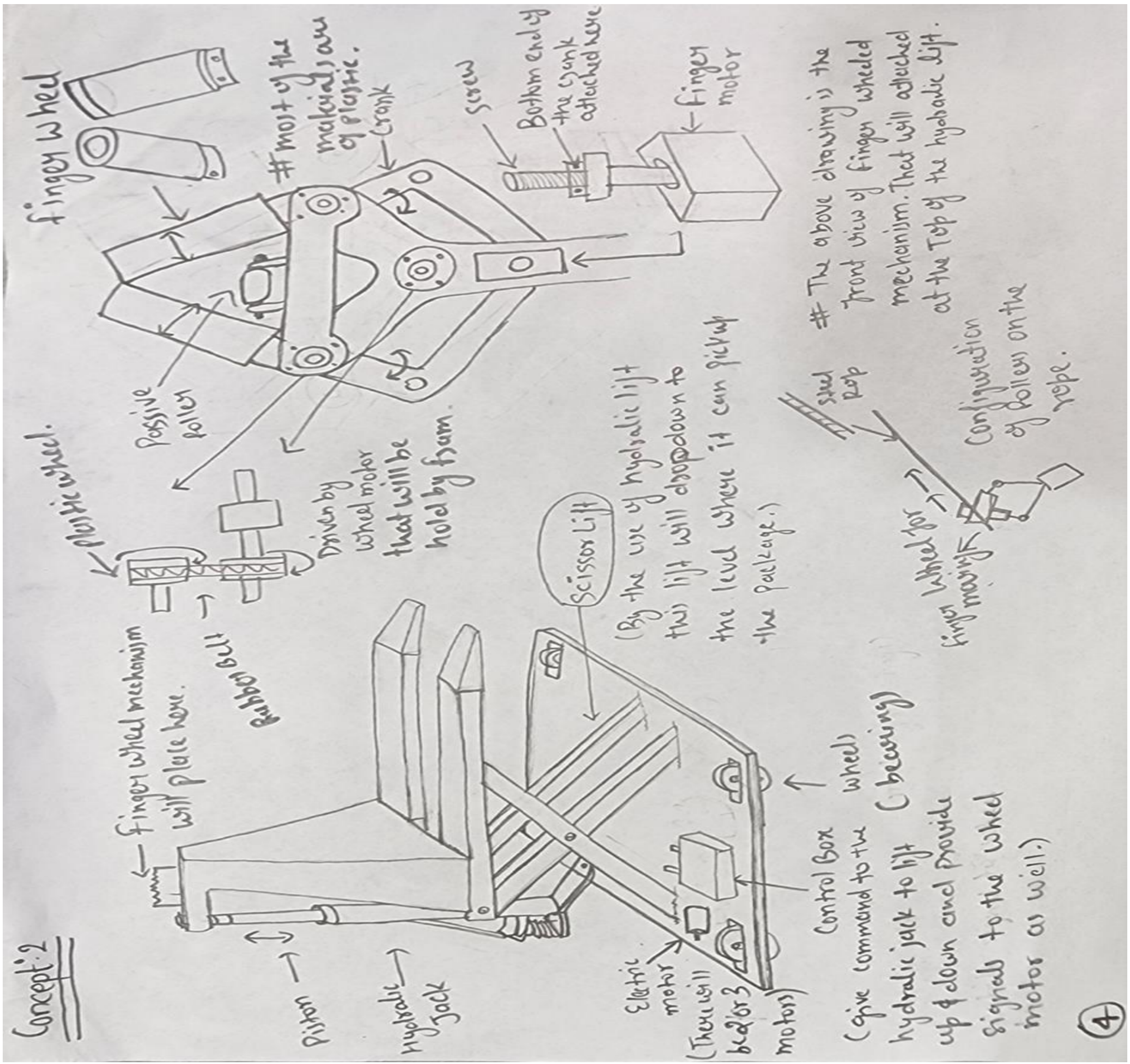


Figure 3: concept 2

Concept 2 is based on fork lift design i.e. it lifts the package by the fork and travels to the pylon 1. And the lift the package to the wire, the lift design has a finger wheel design roller to travel across the deposit zone. Then, it deposits the package than return to start zone.

Limitations

This concept has a major flaw i.e. same as scissor design. And the system would be too heavy to build an actual forklift design. So, this concept as not taken a final concept for our Warman design.

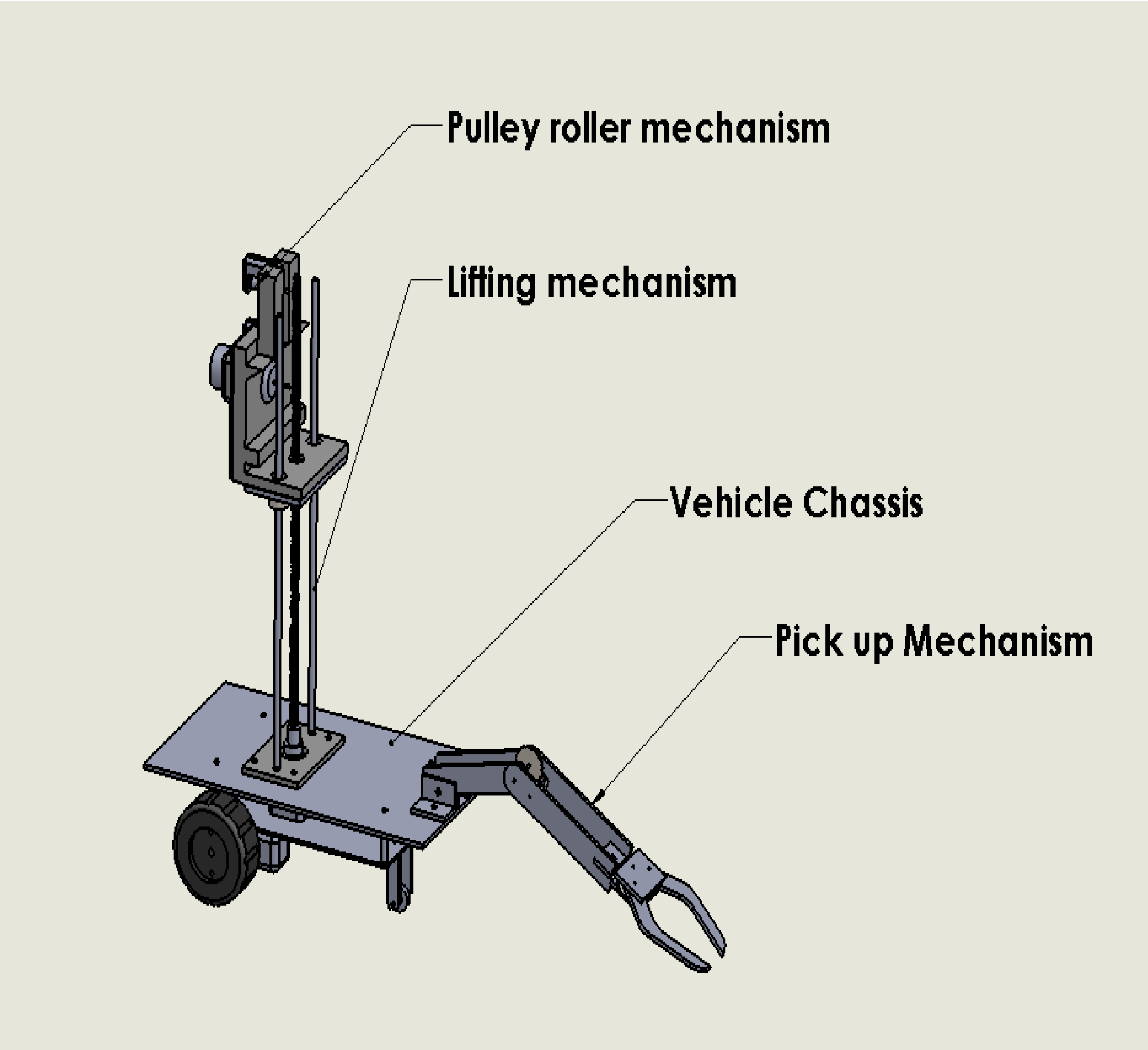


Figure 4: CAD design of final design or Concept 3

Concept 3 is based on the Car chassis design where all the mechanism is mounted on the chassis top. This device has robotic arm, linear actuator and roller mechanism which is driven by pully. All the mechanism and their manufacturing are described below.

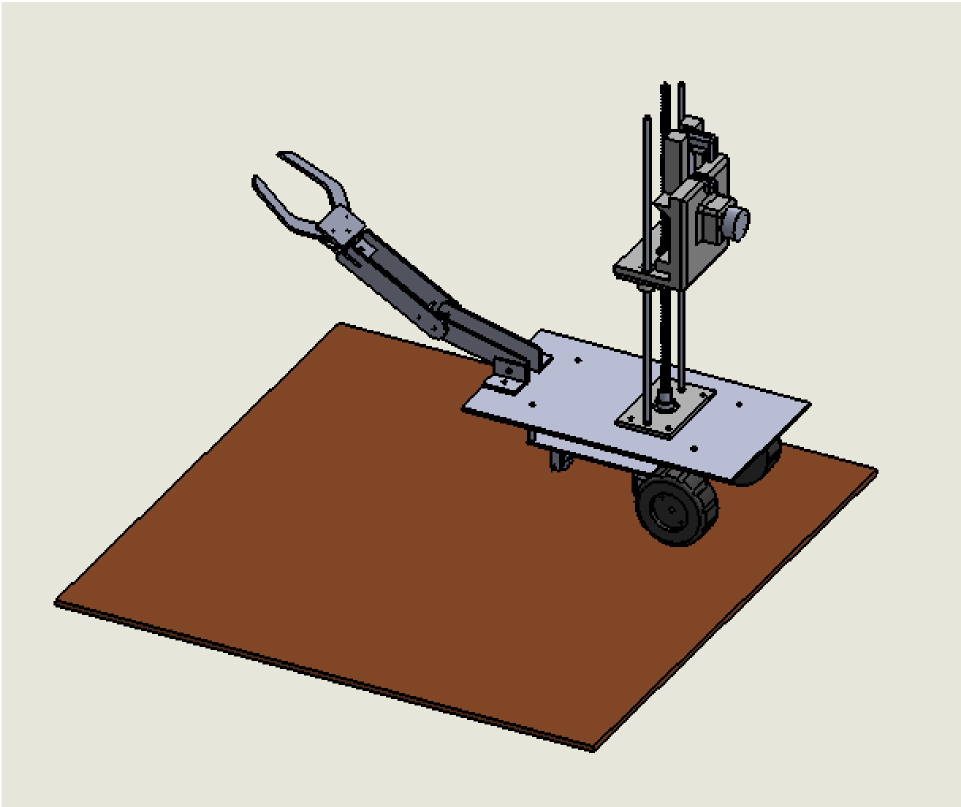


Figure 5: stage 1 gripper grabbing package

STAGE 1

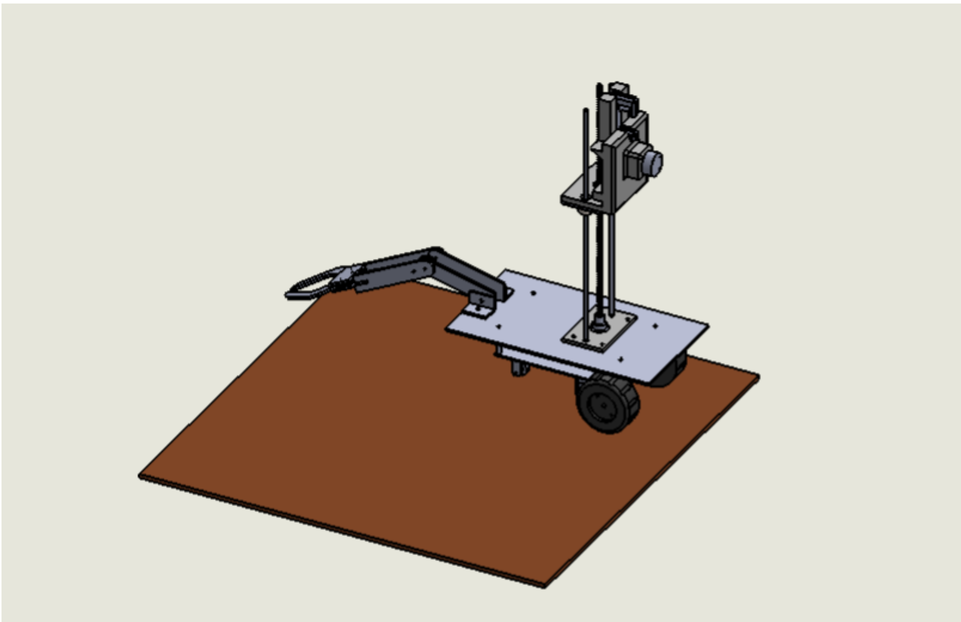


Figure 6: Retiring to Pylon 1 to perform lifting of actuator after grabbing package.

STAGE 2

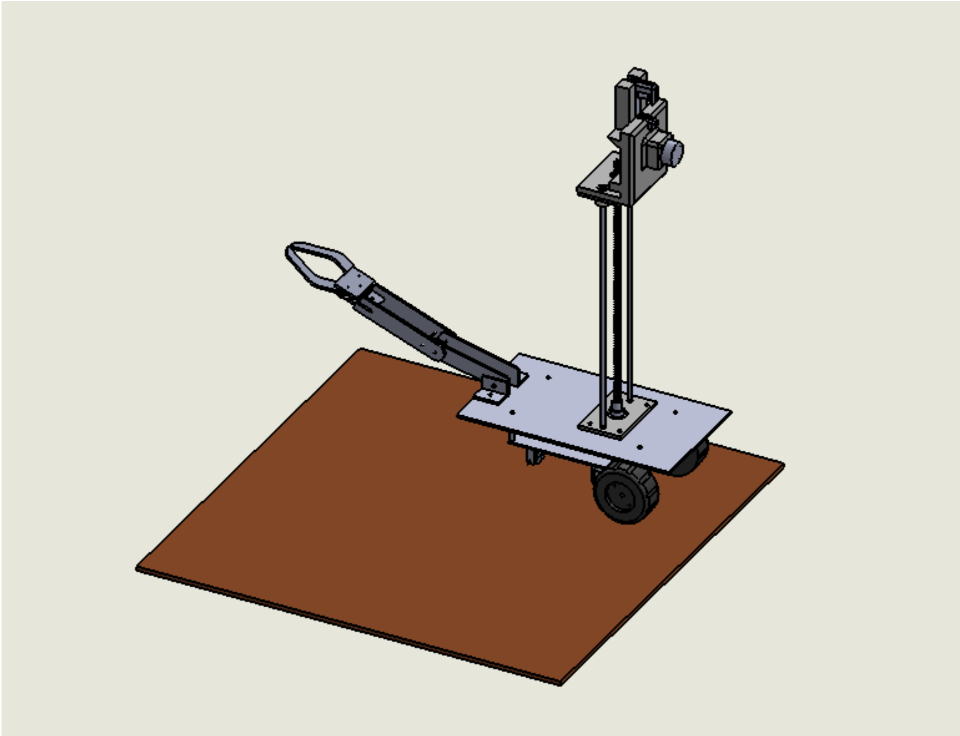


Figure 7: Actuator is moving upward to hook roller on the wire.

STAGE 3

Manufacturing

We used to manufacture process for this device building Leaser cutting and resin printing. All the MDF used on arms and chassis were leaser cut. And as for the actuator frame and all the roller frame and roller were resin printed.

Figure 8: Resin printing of roller frame and roller

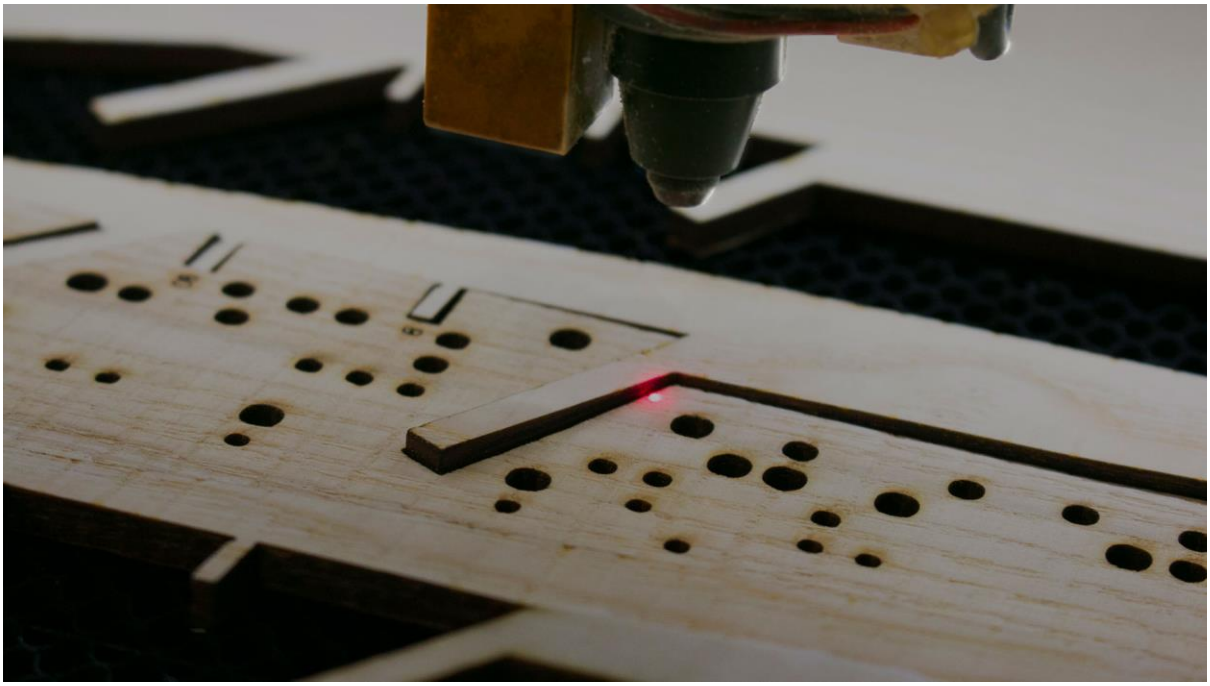


Figure 9: leaser cutting of MDF to make Arm and Chassis parts.

Evaluation Table

Score: 1= Bad, 2= medium and 3= Good

Criteria »	ACCURACY AND RELIABILITY	COST	MATERIALS AND WEIGHT	DEVELOPING TIME	ERGONOMICS	SAFETY	TOTAL SCORE
Percentage	0.2	0.2	0.2	0.15	0.1	0.15	
CONCEPT 1	2	1	2	3	2	2	2.05
CONCEPT 2	1	2	2	2	1	2	1.7
CONCEPT 3(FINAL)	3	2	3	2	3	3	2.65

Total score= (0.2*3) +(0.2*2) +(0.2*3) +(0.15*2) +(0.1*3) +(0.15*3) =2.65

Which is the highest from the table and most suitable to build.

Cost analysis

System Components	Estimate Cost
1 DC Motors	$32
Car Chassis	$10
Tyres off the shelf	$8

Threaded shaft	$10
Servo motors *2	$60
Roller cover and Roller (resin printing)	$20
Screws and Bolts	$10
Robotic Arm elbow and Gripper	$92
Arduino	$35
Batteries	$20
Workshop	$80
Glue	$15
Total	$392

Total cost of building device was 392 dollars which can be seen from table.

Robotic Arm

Robotic Arm is one of the most crucial parts of the Robotic Cable Car. The fundamental function of the arm is to pick the package from warehouse and drop it into the delivery zone. This process of delivery involves the device to linear elevate keeping itself balanced. The device moves as a cable car on the steel wire holding the package in the claws and then dropping it into the desired delivery zone. The other artefacts of the device are fixed in such a way that its centre of gravity is balanced which provides smooth motion. The robotic arm is away from the warehouse boundary fulfilling the constraints.

Robotic Arm Mechanism

Robotic Arm constitutes of a Fixed Arm base, Moving Upper Arm and Gripper. These members are connected by shafts and gears that produce movements. Fixed Arm Base is connected to the chassis of the car. Fixed arm has an angle of 60 degrees with the chassis that provides elevation to the arm. A gear is attached to the fixed arm permanently with glue. Fixed arm is connected to the movable Upper arm that can rotate from 0 to 180 degrees. A servo motor with Spur Gear attached to the shaft is connected to the Upper Arm. The Servo motor rotates the Spur gear that is in transmission with the fixed arm gear. It results in the movement of upper arm.

Upper arm is linked to Gripper that comprises of claws and gears. Servo Motors are used to rotate the gears that generates motion in the Robotic arm. Gripper is fixed with moving arm and only gripper’s jaws can move to grab the package. One Spur gear is glued to one of the gripper’s jaws. Second jaw is linked to another rotatable spur gear with Servo motor. The servo motor attached to the upper arm moves the arm down. The second servo motor, attached to the gripper will close the jaws and hold the package. The upper arm lifts the package and device carries the package with it. The same phenomenon happens when package needs to be delivered. The upper arm moves down, and gripper drop the object in delivery zone.

Both servo motors need to be controlled by a microcontroller to perform this task. Arduino Uno is used in the robotic arm to control motion. Arduino Compatible Motor Servo Controller Module is used to control both motors. This Arduino Shield provides space for other motors to be controlled by the same microcontroller. Arduino IDE is used to program the micro controller according to requirements and motor performs accurate movement. Digital input 9 and 10 are connected to the two servo motors of gripper and arm. These servos are then controlled by Arduino in accordance with requirements.

Material Selection

Selection of material plays a critical role in providing strength to the overall structure. Weaker material can cause the arm to brittle which will result in failure of the device. The material should be light and strong enough to perform desired task. It should be readily available in the market at lower cost. The following score table provides the fundamental requirements of the chosen material including time taken to cut or mould the material, weight of the material, strength, and cost of material.

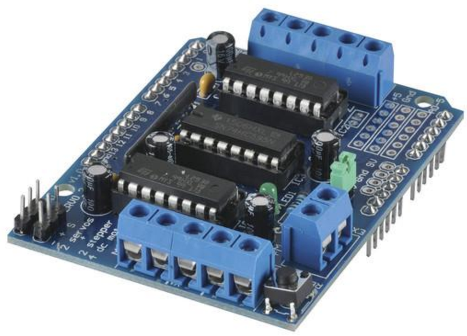
Material	Cost	Strength	Weight	Standard Time	Total Score
MDF	5	3	5	5	18
Steel	3	4	1	3	11
Acrylic	4	2	2	4	12
Resin Printing	1	3	3	2	9
Carbon 3D Printing	2	5	2	2	11

The above table depicts MDF as the score winner. The above parameters in the table are especially important. MDF with 3mm diameter is selected and will be laser cut for the assembly of the robotic arm. MDF is super cheap and a durable material. It has density of 600 kg/m3 making it very lightweight. MDF laser cutting is amazingly fast while 3D printing is slower than laser cutting. This factor reduces the time to prepare the device to perform desired tasks. The whole Robotic Arm assembly is made by MDF sheet of 3mm Diameter. The gears are made of plastic and steel shafts are used in the arms.

Components Analysis

Robotic arm constitutes of many components with their specific functions and roles to achieve required goals. The following are portrayed in the table below

Components	Specifications	Pictures
Servo Motor for Gripper	Protocol: Pulse Length Modulation Voltage: 5V Additional Features: 3.5V-6V Supply Voltage 500 degrees/second at 6V 1.6kg.cm at 4.8V Weight: 9g Torque: 1.6 kg.cm at 4.8V Cost: 11.95$ (“Arduino Compatible 9G Micro Servo Motor,” n.d.)	 (jaycars, n.d.)
Servo Motor for Arm	Servo torque: 10.5kg.cm at 4.8V Gear Material: Metal Weight: 55g Operating Temperature: 0C-50C DC Voltage: 4.8V-7.2V Motor Nominal Voltage: 6V No load RPM: 58RPM Full load torque: 13kg.cm Full load current: 1.2A No load current: 170mA Cost: 39.95$ (“Servo Motor - Standard 6 Volt with Metal Gear - 13kg,” n.d.)	 (jaycar, n.d.)

Spur Gears	Material: Plastic Type: Gear Set Component Gear Teeth: 48/12 Cost: 12.95$ ("Gear Set and Spur Gear Set," n.d.)	 (jarcar, n.d.)
Servo Controller Module	Current rating per channel: 0.6A (1.2A surge) Logic input: 3V – 5V Operating Voltage: (External Power) 5V – 30V Chipset: 74HC595 & L2930 Cost: 12.95$ ("4CH Motor Controller," n.d.)	 (jarcar, n.d.)
MDF Sheet	Thickness: 3mm Elastic Modulus: 4.0GPA Shear Modulus: 2.5GPA Tensile Strength: 18 MPa Density: 0.75g/cm^3 Cost: 8.65$ (Medium Density Fiberboard,2020)	 (Bunnings, n.d.)

Testing and Calculation

Testing the robotic arm is very crucial process. During testing of the robotic arm, many failures were faced. The robotic arm was then modified accordingly. Many learnings were achieved while testing the device. The problems faced are following

- Gears failed to lift the package up
- Shaft broke due to the weight of the arm
- Less torque and power motors used to perform desired tasks
- Bending moment in the arm while lifting the package

Countermoves were used to make robotic arm function properly. Those actions are following as

- High Power servo motors were used with high torque and metal gears which provided enough torque to the arm to lift package up.
- Steel shafts were used that provide strength to the arm
- The device was balanced according to its centre of gravity and calculations. This made the device stable while lifting and moving the package

After these countermoves robotic arm performed the objective without any glitch.

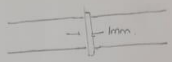
The stress analysis and safety factor calculation of robotic arm the following

- The shafts are in a critical stress position, and they face high shear stress and bending moment. So, stress analysis of arm shafts is very essential. Safety factor of shafts is calculated that is far more than 2. This makes Robotic Arm safe, strong, and stable. Steel shafts used in arm are strong enough to hold the object and move it. The below calculations display the safety factor of shafts.
- Fixed arm is permanently fixed with car chassis with help of glue. This part is subjected to normal stress and bending moment. A safety factor of 1.55 was achieved here. Since it was less than 2 we used to support to hold the fixed arm. Supports were fixed with screws into the chassis. It gave required strength and stability to the fixed arm.
- Gripper was fixed with the upper arm permanently by screws as well. the safety factor for the gripper was far greater than 2 which makes it very firm

①

Calculation:-

Shear Stress & S.F for pins in Arms:



Area of pin = $\frac{\pi d^2}{4}$

d = 1mm.

$= \frac{\pi (1)^2}{4} = 0.785\ mm^2$.

Total mass of Arm $(m_t) = 0.135$ Kg

Total weight = mg

$= (0.135)(9.81)$.

Total weight = 1.3245 N.

Max. Shear Stress $= \frac{V}{A} = \frac{1.3245}{2(0.785)}$

multiply Area by "2" because pin is connecting both side of the arm.

②

$\tau_{(max)} = \frac{1.3245}{1.57} = 0.844$ MPa.

Safety factor $= \frac{\sigma_{sy}}{\tau_{max}} = \frac{0.577 \times 170 MPa}{0.844\ MPa}$

= 116.

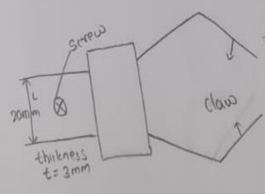
⇒ Claw holding Screw Shear S.F:

mass of the claw $(m_{claw}) = 0.034$ Kg

weight of the claw $(W_{claw}) = m \times g$

$= 0.034 \times 9.81$

$= 0.334$ N.



③

t = thickness of mdf = 3mm

L = 20mm.

Area of Claw = t x L

= 3 x 20

= $60\ mm^2$.

$\tau_{(max)} = \frac{W_{claw}}{A_{claw}} = \frac{0.334}{60} = 5.6 \times 10^{-3}$ MPa.

S.F $= \frac{0.577 \times 10 MPa}{5.6 \times 10^{-3}}$

S.F = 1030

(4)

Safety factor for Glue Section of Fixed Arm:-

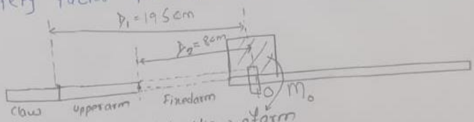


fig: Side View of arm

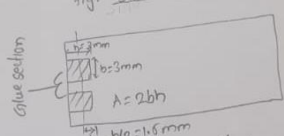


fig: Top view of glue section (attached to fixed arm)

$mass_{claw} = 0.034$ Kg.

$m_{upp Arm} = 0.12$ Kg.

S.F $= \frac{S_y (glue)}{\sigma}$

$\sigma = \frac{F}{A} + \frac{MY}{I}$.

$\circlearrowleft^{+} \Sigma M_o = 0$.

$M_{claw} \cdot D_1 + M_{upp. Arm} \times D_2 - M_o = 0$.

$M = (0.034 \times 9.81 \times 19.5 \times 10) + (0.12 \times 9.81 \times 8 \times 10)$

$M = 65.0403 + 94.176$

M = 159.2163 N.mm

(6).

$$S.F = \frac{\sigma_y(\text{glue})}{\tau_{max}}$$

$$= \frac{27.54\ MPa}{17.75\ MPa}$$

$$= 1.55 < 2.$$

"So due to less "S.F" we will use screws to hold the fixed arm in each side".

Car Chassis

The car chassis is the most fundamental part of our device that holds all the weight. The chassis has to travel a certain distance from the starting location to the delivery zone. To achieve the main objective, the car chassis has to be within starting zone, not in the warehouse boundary; otherwise, it will be against the rules of the competition. After picking up the package from the warehouse, the car chassis will hang on the roller from the starting zone to transport the package without touching the chasm zone to the deposit zone at D.

Mechanism

The car Chassis is made up of an MDF sheet balanced from two rubber tyres at the back and one ball bearing at the front. The DC motor has been attached to each back tyre to help the chassis move forward and backward. The linear actuator and robotic arm have been fixed with screws and glue at the top of the chassis. Three wheels elevate the chassis from the ground, one in the front-mid and two at the rear.

Furthermore, Dual-sided tape has been used to adjust the power supply and Arduino on the chassis. Furthermore, Dual-sided tape has been used to adjust the power supply and Arduino on the chassis. Two 33mm radius wheel has been installed at the backside of the chassis and DC motors with a 10V voltage.

Material Selection:

Based on the key design characteristics, multiple systems for transporting the package around the track were discovered. This included determining the drive motor and wheel/track to use. To make this judgement, following tables were used.

1=Bad 2=Medium 3=Good

Criteria	DC motor	Stepper motor	Servo
Total Cost	3	2	1
Power Efficiency	3	1	2
Torque Level	1	3	2
Ease of code	3	1	2
Total	10	7	7

Criteria	Rubber wheels	Regular wheels	Micro wheels
Total Cost	3	1	1
Total Mass	3	1	1
Movement	2	3	1
Mounting	2	2	3
Total	10	7	6

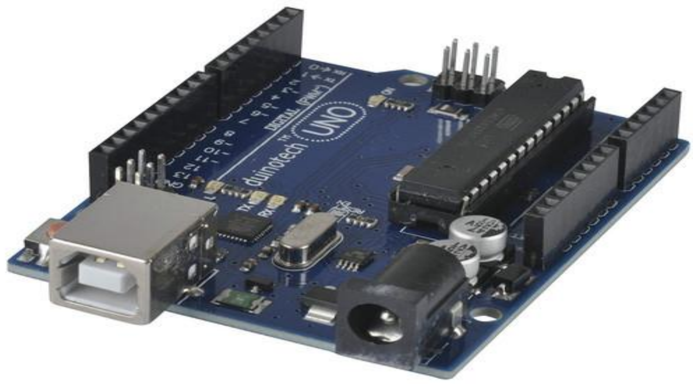
DC motors were the best choice for the project. DC motors are the least expensive commercial motors on the market. DC motors can be driven by merely applying a voltage across their terminals, and they can attain higher speeds with less torque than conventional motors. DC motors can also be differentially operated by varying the voltage amplitude and polarity. This will work for this project since the car can reverse from the warehouse to starting zone and then back to Position D to A at the deposit zone.

Rubber wheels were the most excellent match for the project. Wheels with additional functionality (such as Regular-wheels and micro wheels) were unnecessary due to the simple mobility on the track. Tracks would not be necessary for high traction because the track is made of dry wood (which has superior friction). Tracks also require many accuracies to perform successfully (e.g., motors aligned, tracks and wheels flush), which is impractical for a low-budget project like this. Also, regular wheels and micro wheels that are either made of cheap material or poorly produced do not operate properly, based on previous experience.

Component Analysis

The car chassis also consists of some other components described below in the table.

Components	Specifications	Pictures
DC Geared Motor with Rubber Wheel	• DC Nominal Voltage: 10V • Gear ratio: 48:1 • Free current: 70mA@3V • Stall current: 250mA Torque: 800gf.cm • Material: plastic tyre ("DC Geared Motor with Rubber Wheel," n.d.)	 (jaycar , n.d.)

MDF Sheet	Thickness: 3mm Elastic Modulus: 4.0GPA Shear Modulus: 2.5GPA Tensile Strength: 18 MPa Density: 0.75g/cm^3 Cost: 8.65$ (Medium Density Fiberboard,2020)	 (Bunnings, n.d.)
Arduino UNO	ATMega328P Microcontroller o EEPROM: 512 bytes o Speed: 16MHz • ATMega16u2 USB-Serial Chipset • IO: o Digital IO: 14 pins o PWM Capable: 6 pins o Analogue Inputs: 6 pins • Input voltage: o 7-14VDC via Vin pin o on board 5V Input • USB Cable connection	 (jaycar , n.d.)

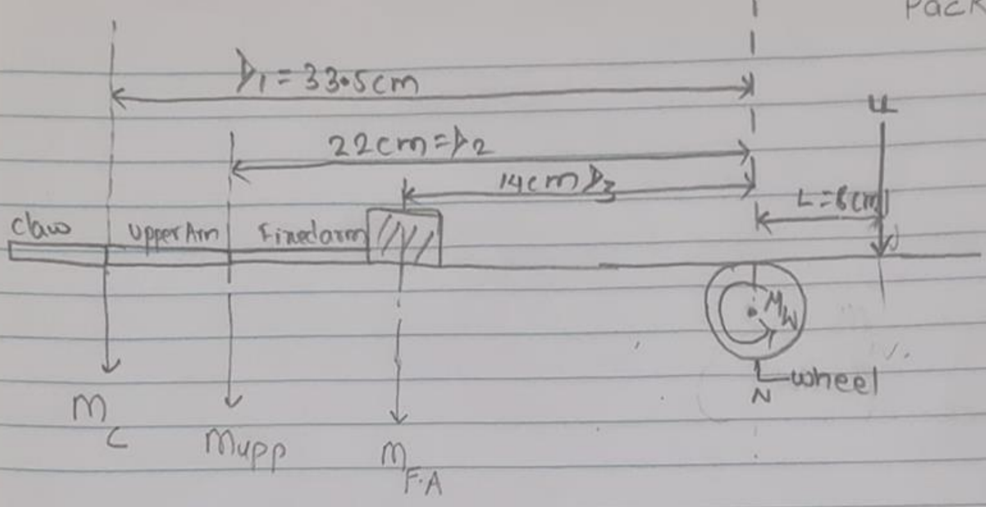
Testing and Calculation

Testing is an essential component before operating any device, whether it is safe to use and fulfil the requirement. We have not faced any failures for the car chassis, but at the start, the motor we used was not powerful and later, two DC motors with 10V voltage were used, which got more power and a high torque.

Secondly, the two back wheels were connected with a single shaft, which got some space and caused issues in operating the chassis properly. Later on, the group addressed these issues, and with some changes the chassis was operating efficiently.

For the car chassis, total load analysis on the car chassis has been calculated. The two rear wheels hold the overall load of the device and moment has been calculated for the claw, upper arm, fixed arm, rear wheel to analyse the force on the wheels, fixed arm, rear wheel to analyse the force on the wheels.

Car Chassis: (1) Load Required For Balancing Package:



Considering tot. mom. of system $\Sigma M_W = 0$.
(from the rear wheel).

Mom. in claw = $W \times D_1$

$= mg \times D_1$

$= 0.034 \times 9.81 \times 33.5 \times 10$

m_{claw} $= 111.74$ N.mm.

~~$m_{upp.Arm} = W \times D_2$~~

~~$= \{(mg \times D_1)_{claw} + (mg \times D_2)\} D_2$.~~

~~$= (111.74 + 0.086 \times 9.81)(22 \times 10)$~~
~~0.034×9.81~~

~~$= (112.58)(22 \times 10)$~~

$m_{upp.Arm} = W_{upp.Arm} \times D_2$.

$$M_{upp.Arm} = (m_c + m_{upp})g \times D_2.$$

$$= (0.034 * 0.086)\ 9.81 \times 22 \times 10.$$

$$= (0.12)(9.81)(22 \times 10)$$

$$\boxed{M_{upp.Arm} = 258.984\ N.mm}$$

Moment in Fixed Arm $= W \times D_3.$

$$= mg \times D_3$$

$$= 0.135 \times 9.81 \times 14 \times 10$$

$$\boxed{M_{F.A} = 185.409\ N.mm}$$

$$\circlearrowleft^{+} \Sigma M_W = 0.$$

$$M_c + M_{upp.Arm} + M_{Fix.Arm} - F \times L = 0$$

$$F = \frac{111.74 + 258.984 + 185.409}{6 \times 10.}$$

$$\boxed{F = 9.27\ N.}$$ OR

$$\boxed{m = \frac{9.27}{9.81} = 0.95\ kg}$$

Linear Actuator with Roller

Linear actuator is responsible for the linear upward and downward movement of the device. A roller mount is attached to the actuator that moves up and down on the actuator. The roller rolls on steel wire and device moves along with the roller. Linear actuator moves the roller mount up to the wire, where roller starts rolling on the steel wire. The actuator lifts the whole device up in air and then it moves from start zone to delivery zone. The linear actuator then moves the device down to the ground where the device drops the package. Similarly, the device follows the same procedure when going back to the start zone.

Mechanism of Linear Actuator

Linear actuator constitutes of one threaded shaft, two flat linear shafts and a stepper motor. These are the main parts of actuator which makes it functional. The threaded shaft is connected to the stepper motor. A coupler is used to connect the threaded shaft to the stepper motor. The other two steel shafts are utilized to support the threaded shaft. These shafts give strength to the actuator and provides stability. The stepper motor is fixed in inside the chassis of the car. When it is connected to the power source, threaded shaft rotates along with the motor's shaft where the two supporting shafts remain stationary. The stepper motor is connected to the Arduino servo motor shield and its number of revolutions are controlled by microprocessor. Arduino controls the elevation of the roller mount by controlling the RPM of the stepper motor. The supporting shafts are threaded at one end which passes through the car chassis. These shafts are locked by nuts restricting their movement.

Mechanism of Roller

Roller is formed by roller mount and roller itself. The whole artefact is 3d printed by resin. Roller is designed according to thickness of the steel wire so it can roll easily on the wire and can transport the whole device from one zone to other. Roller is fixed with roller mount so it can only produce rotational motion. The roller mount is fixed on to the linear actuator and it will move up and down as threaded shaft rotates. Roller mount base has three holes for linear actuator's shafts. Threaded shaft passes through the middle while the two holes on side hold flat linear shafts. Mount base middle hole is threaded from inside. The other two holes has bearings inside which makes sliding easier for flat linear shafts. As the threaded shaft rotates, roller mount moves up and down depending upon the direction of rotation. In this whole process, flat linear shafts hold the linear actuator firm. The roller rotates with a pulley system. Roller is connected to a high torque DC motor by a pulley. Pulley sets are used to ensure smooth movement of roller on the wire. A rubber belt is used as a pulley here to rotate roller. The DC motor is connected to the Arduino Compatible Motor Shield which controls the direction of rotation, speed, and RPM.

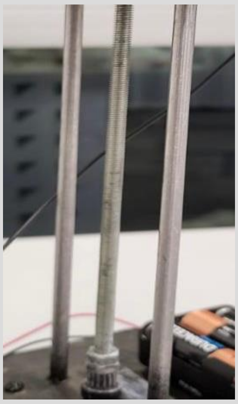
Material Selection

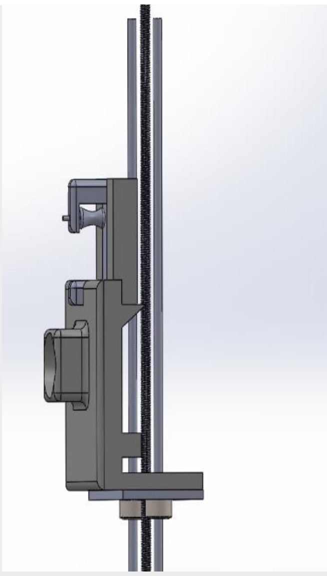
Selecting material for linear actuator was easy keeping the constraints and objectives in mind. Steel threaded shaft was used as it was easily available in the market. Two flat linear shafts were also available in any of the tool shop. Getting theses shafts from market instead of 3d Printing them saved a lot of time and cost. As the shafts needed had to be strong, steel shafts fulfilled that requirement.

In case of roller and roller mount, the whole artefact is designed according to device needs. Roller and roller mount were 3d printed by resin as carbon fibre 3d printing was not available at that period. Resin is a relative strong material but not stronger than carbon fibre 3d printing. Roller was fixed permanently on the mount with shafts.

Components Analysis

The table below depicts the components used and their characteristics:

Components	Specification	Images
Flat and Threaded Shafts	Material: Stainless Steel 316 G Density: 99 g/cm3 Thermal Expansion: 9mm/m/°C Electrical Resistivity: 4µohm/cm Thermal conductivity: 3W.m -1.°K-1 Modulus of elasticity: 193 GPa (Mitchell, 2018)	

Roller and Roller Mount	Material: Resin 3d Printed Tensile strength: 55.7 MPa Flexural strength (at 5% strain): 60.6 MPa Flexural modulus: 1.6 GPa Elongation at break: 24% Notched IZOD impact strength: 38 J/m (Know Your Materials: SLA Tough Resin | Fast Radius, 2022)	
DC Motor	Max. efficiency current: 3.2A Full load torque: 75kg.cm Full load current: 18A Max efficiency RPM: 134RPM Motor Nominal Voltage: 12V Maximum efficiency torque: 11.84kg.cm (55RPM 12VDC Reversible Gearhead Motor | Jaycar Electronics, 2022)	
Pulley Set	Material: Plastic Pulleys diameter: 50mm, 25mm, 11 mm Accessories: Rubber, Brushings, Screws and Nuts	

Failures and Learnings

- While testing the linear actuator, compatible DC motor for the roller's desired task was hard to find. Hight torque is needed to move the device from start zone to delivery zone. This task cannot be achieved by low power motors with less torque. We used a highly efficient DC Motor for this purpose which solved the issue of transportation
- The roller mount was 3D printed from resin, which was strong enough, but it was printed hollow to make it lightweight. The roller mount broke during testing due to the excessive load and tensile stress. To counter this issue, we 3d printed the whole roller mount again without making it hollow.
- Another problem was to maintain the stability of the device when it hangs on the wire. Stability of device is very important in the whole process. To make it stable, we worked on the centre of mass and centre of gravity of the car. The loads are placed in such a way that it shall balance the whole device

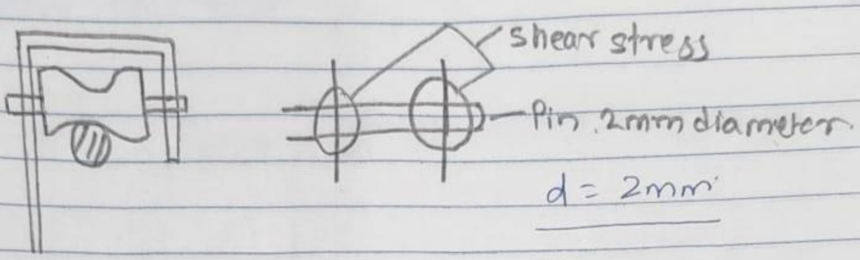
Calculations

The stress analysis and other calculations are done for the linear actuator, which follows as

- When the device hangs on the wire, all the weight of the device is balanced by the roller. It makes roller a critical point for stress analysis. The shafts of roller are subjected shear stress in case of rolling on the wire. The safety factor is calculated which is more than 2 making it safe for functioning
- The rods of the linear actuator go through shear stress hence, its safety factor must be calculated which far more than 2
- The position of roller mount on the actuator is a critical point as it has normal stress acting on it and there is bending moment as well. The combined safety factor is very high than 2
- Roller also goes through compression as it moves from one zone to other. The safety factor is calculated which is more than 2 making the roller durable to use.

①

Shear Stress in Roller pin & Saf. fac:-



Total weight of the device = 1.93 Kg.

Shear pin Area ($A_{roll \cdot pin}$) $= \frac{\pi}{4} d^2$

$= 3.14 mm^2$

$$\sigma_{(max)} = \frac{V_{tot}}{2 \cdot A_{roll \cdot pin}} = \frac{1.93 \times 9.81}{2 \times 3.14}$$

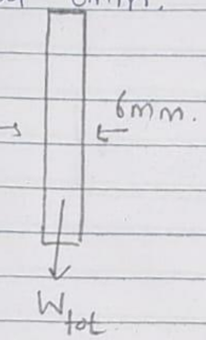
$= 3.015 N/mm^2$

$$S.F(n) = \frac{\sigma_{S.Y}}{\sigma_{max}} = \frac{0.577 \sigma_{S.Y (pin)}}{3.015 \text{ MPa}}$$

$$= \frac{0.577 \times 170}{3.015} = 32.$$

Shear Stress & Safety factor on Rods of Actuator:-

Diameter of Rod = 6mm.



Mass of the one Rod = 35

" " 3 Rods = 3x 35

= 105 g. = 0.105 kg.

Weight of 3 Rods = W_t = 0.105 x 9.81

= 1.03 N.

Area of 1 Rod = $\frac{\pi d^2}{4}$

Area of 3 Rod = $3 \times \frac{\pi d^2}{4}$

$= 3 \times \frac{\pi (6)^2}{4}$

$A_t = 84.82 mm^2$

Max Stress $= (\sigma_{max}) = \frac{F}{A} = \frac{W_t}{A_t} = \frac{1.03 \times 9.81}{84.82}$ (total / whole weight of device)

$\sigma_{max} = 0.223$ MPa

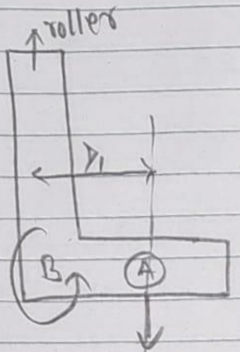
(2).

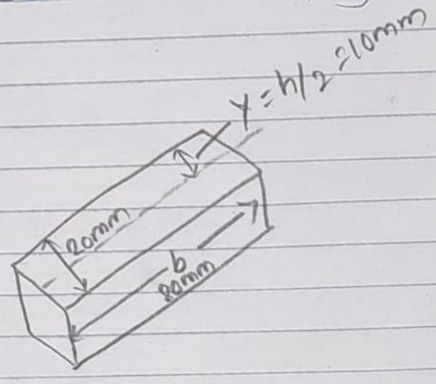
$$S.F(n) = \frac{\sigma_{Y(steel)}}{\sigma_{max}} = \frac{170}{0.223}$$

$$\boxed{n = 762.}$$

(1)

Actuator Frame Stress & Safety factor:-





(Side veiw)

Stress at point (A) $= \frac{F}{A} = \frac{mg}{A(h \times b)}$

$= \frac{1.93 \times 9.81}{20 \times 80}$

$= 0.0118\ N/mm^2$

Stress at B due to Mom. $= \frac{MY}{I}$

$= \frac{(W_{Frame} \times D)(h/2)}{\frac{1}{12} b \times h^3}$

$= \frac{1.93 \times 9.81 \times 218 \times 20/2}{\frac{1}{12}(80 \times 20^3)}$

(2)

$$\sigma_B = \frac{473.3325 \times 10}{53333.33}$$

$\sigma_B = 0.088 \ N/mm^2$

Total Shear Stress $= \sigma_A + \sigma_B$

$= 0.0118 + 0.088$

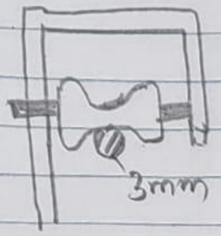
$= 0.0998 \ MPa$

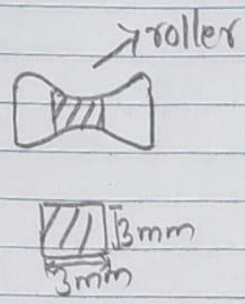
$$S.F = \frac{\sigma_y(\text{Design})}{\tau_{(max)}} = \frac{40 \ MPa}{0.0998}$$

$$\boxed{S.F = n = 400}$$

①

Compression in hanging Roller & S.F:-





mass of the Roller = 0.008 Kg,
total mass of the device = 1.93 Kg.
total Weigh = 18.914N.

Area of Compression Roller (A_{roller}) = L x b. ~~F / A_{roller}~~

~~$\frac{m_{tot} \times 9.81}{9mm^2}$~~

$= 3 \times 3 = 9mm^2$

Cal. Compression stress $= F/A_{roller}$

$= \frac{m_{tot} \times 9.81}{9}$

$= \frac{1.93 \times 9.81}{9} = 2.10 \, N/mm^2$

(2)

$$S.F\ (n) = \frac{\sigma_y\,(\text{roller})}{\sigma_{com}}$$

$$= \frac{40}{2.10}$$

$$\boxed{n = 19.04}$$

Arduino codes

```
/* Sweep
S by BARRAGAN <http://barraganstudio.com>
 This example code is in the public domain.

 modified 8 Nov 2013
 by Scott Fitzgerald
 https://www.arduino.cc/en/Tutorial/LibraryExamples/Sweep
*/
//Library for Stepper
//Library for the DC motor
#include <AFMotor.h>

//Library for the servo motor
#include <Servo.h>

//Objects for the jaw and arm.....................................................
Servo myservoArm;  // create servo object to control a servo                   .
Servo myservoJaw;  // create servo object to control a servo                   .
//..............................................................................

//.....Stepper MOTOR
AF_Stepper motorStep (100,2);
//...............................

//.....DC MOTOR FOR WHEELS
AF_DCMotor motor(1, MOTOR12_2KHZ);
//...............................

//Distance to be travlled in milliseconds
int movePos = 1000;

void setup() {S
  //Attaching the Jaw and Arm to the Arduino....................................
  myservoJaw.attach(9);  // attaches the servo on pin 9 to the servo object   //Jaw .
  myservoArm.attach(10);  // attaches the servo on pin 10 to the servo object //Arm .
  //............................................................................

  //Set motor speed.............................................................
  motor.setSpeed(96);  //.....From 0 to 255
  //............................................................................

  //Set Stepper motor speed.....................................................
  motorStep.setSpeed(64);  //.....From 0 to 255
  //............................................................................
}
```

```
void loop() {
  //Move towards the object................................................................
  motor.run(FORWARD);
  delay(movePos);
  //.....................................................................................

  //Target found stop
  motor.run(RELEASE);
  //................

  //Catch the object.....................................................................
  //Open the Jaw
  myservoJaw.write(0);
  //Set the arm at the object 'wheel' position
  myservoArm.write(0);
  delay(2000);
  //Close the jaw. Catches the object
  myservoJaw.write(200);
  delay(2000);
  //Lift the object caught
  myservoArm.write(180);
  delay(2000);
  //.....................................................................................

  //Move away from the object............................................................
  motor.run(BACKWARD);
  delay(movePos);
  //.....................................................................................

  //Stop car
  motor.run(RELEASE);
  delay(2000);
  //..

  motorStep.step(200, FORWARD, DOUBLE);
  delay(1000);
  motorStep.step(200, BACKWARD, DOUBLE);
  delay(500);

  stop1();
}

//Infinite Loop
void stop1()
{

       {
         motor.run(RELEASE);
         for(int i=0; i >= -1; i++)
         {
           delay(i);
         }
       }
       /*

       */


       /*
       Grab n Release
       myservoJaw.write(0);
         delay(2000);
         myservoJaw.write(180);
         delay(2000);
       */
```

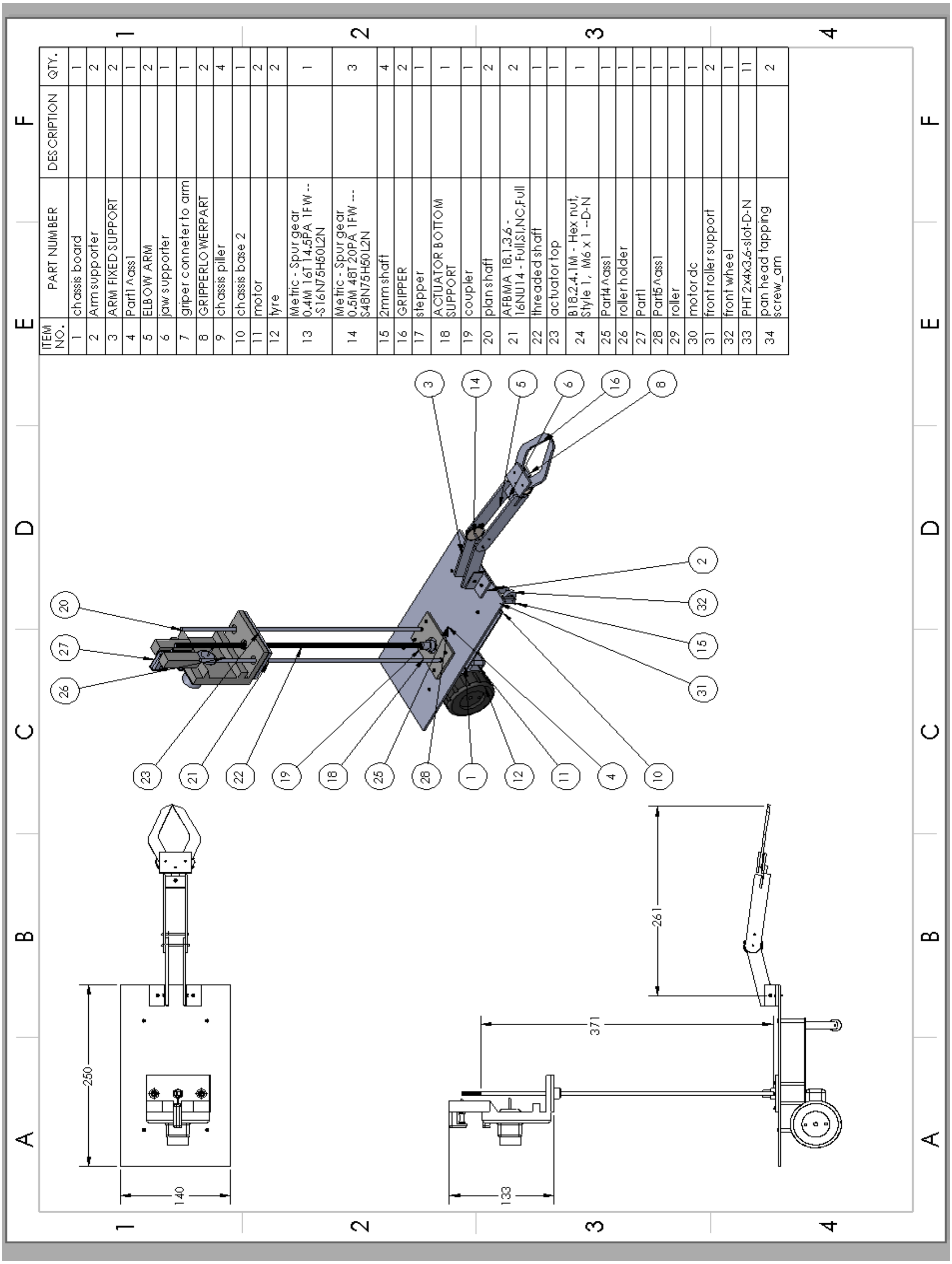


Figure 10 Dimensional view of the device

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