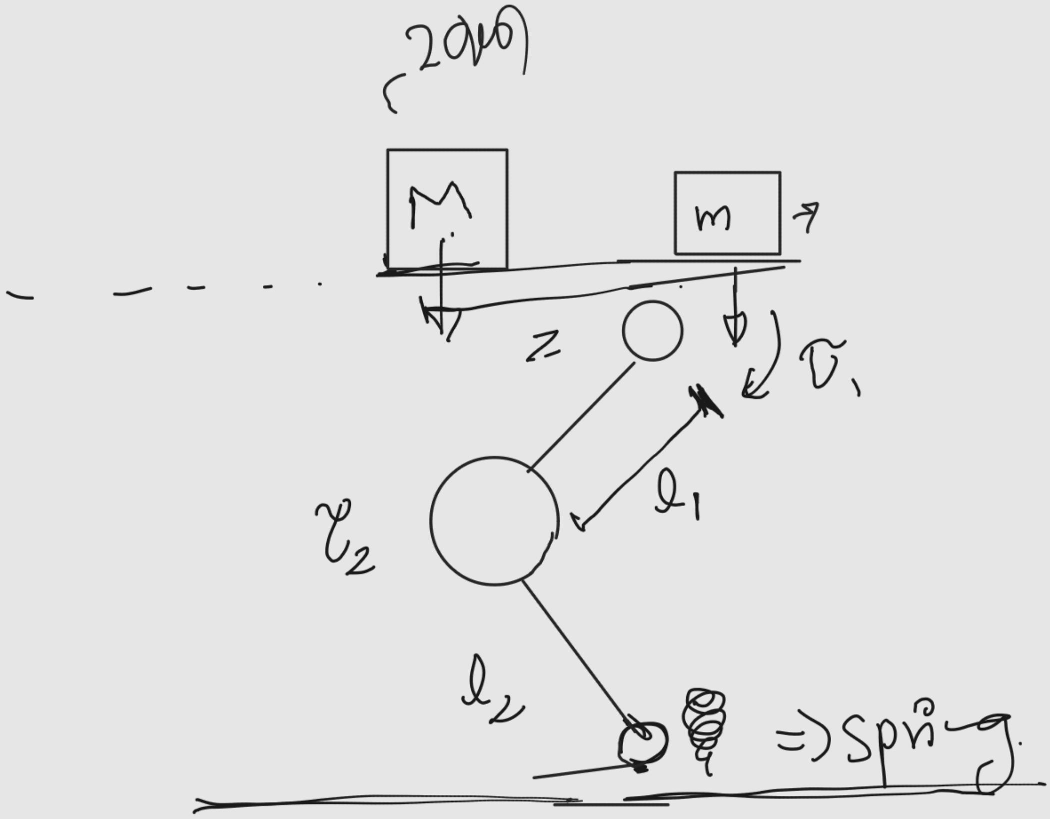
17/04/2024

2972

Team V.P.R.H

Mechanical

Team Lead: Vinay M (20Bmn1049)



The following is torque equations we derived based on few assumptions

#1 The exoskeleton weight is evenly distributed above the knee

The weight of lower part of exoskeleton below the knee is half of the entire weight of exoskeleton

$$\tau_1 = (M \cdot Z + m \cdot Z')g\sin\theta + \frac{e\, l_{hip}}{2}$$

$$\tau_2 = \left(Mg\sin\theta + \frac{e}{4}\right) l_{knee}$$

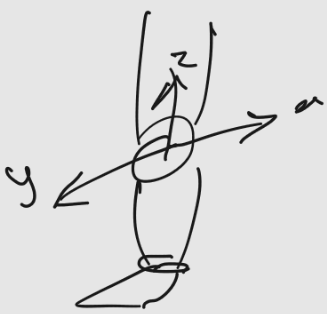
$M \rightarrow$ Mass of box
$m \rightarrow$ Weight of battery
$Z \rightarrow$ Horizontal distance of hip joint to box
$Z' \rightarrow$ Vertical distance of hip joint to centre of battery
$l_{hip} \rightarrow$ length of hip to knee
$l_{knee} \rightarrow$ length of knee to ankle
$e \rightarrow$ weight of exoskeleton

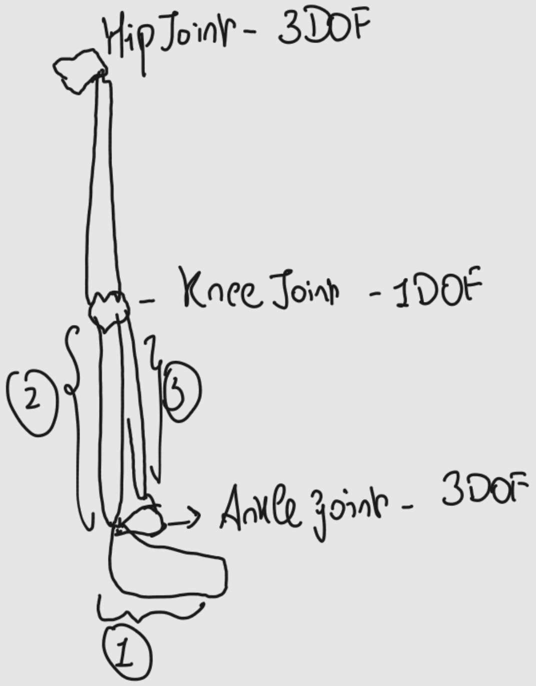
Exoskeleton

1) Joint mechanisms
2) DoF of each part
   (knee, thigh, Ankle)
3) Actuation mechanism
4) Load capacity parameters
5) Limits (mechanical)
6) Battery capacity.
7) Weight support distribution.

Probable Exo material :

$F = Kx$

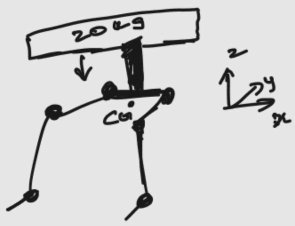




Load bearers - 1, 2 & 3

Actuation Mechanism

Hydraulic   Servo Motor

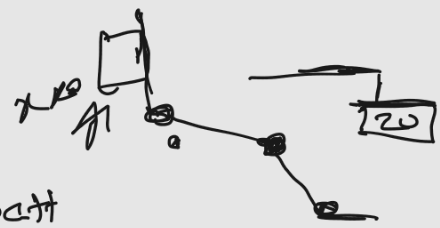


Assumptions:

1) Box / weight always lifted parallel to the body and centered wrt body.

2) C.G located at Hips

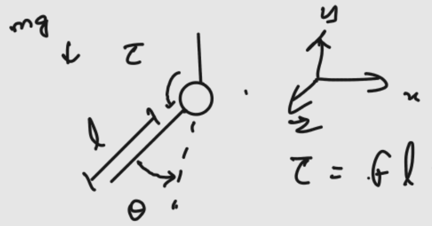
3)



Batt wt $x = 20$ kg

$+ f$

Consideration of Force in one Joint :



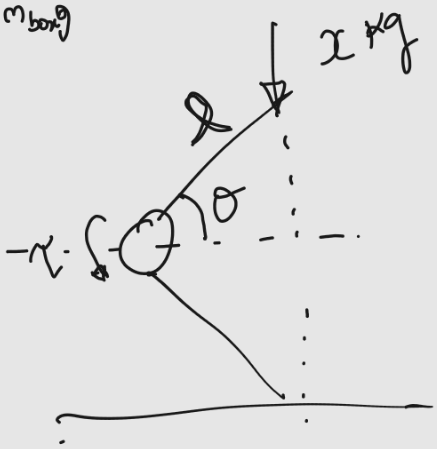
$\tau = f\, l \sin\theta$

x - weight of obj

l - length of the link

e - exoskeleton weight

when lifting the weigh



$F = m(a)$

$F = x(g)$

$F = xg$

$\tau = l \cdot F \sin\theta$

$= l * x(g) \sin\theta(\theta)$

$\tau = l * x(g)\,(1$

$\tau = l \cdot x(g) + e'$

$\tau = g x \cdot (l)$

$: 10\ m/s \times 20$

with e_τ [Exoskeleton]

$\tau = l * (F + E) \sin\theta$

$= l * (x + e) g \sin\theta$

$\tau_{max} = l * (x + e) g$

range-

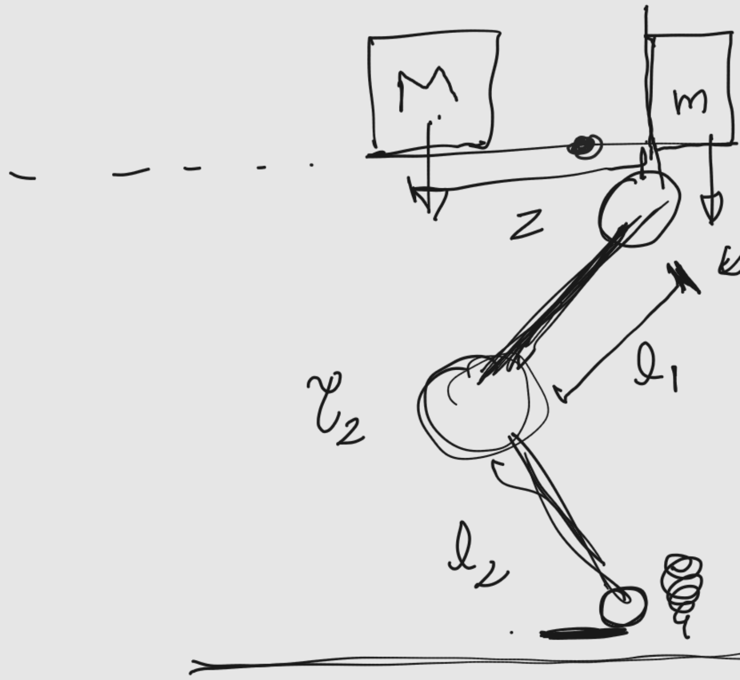
$\sin\theta \begin{Bmatrix} 1 \\ -1 \end{Bmatrix}$

max $\sin\theta$ is 1

So when $\sin\theta$ is 1 the torque will be max

Exoskeleton System.

side view



$M \Rightarrow$ box weight

$m \Rightarrow$ battery weight

$z \Rightarrow$ box distance

$\Rightarrow$ spring to passive joint

$\tau_1 \Rightarrow$ hip joint torque

$\tau_2 \Rightarrow$ knee joint torque

M on $\tau_1 \Rightarrow (Mg)(z)\sin\theta$

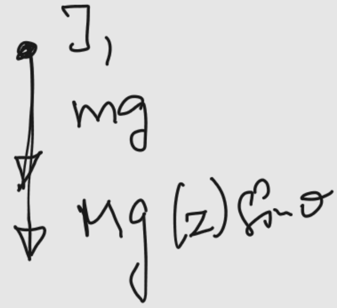
m on $\tau_1 \Rightarrow mg$

$$\tau_1 = (Mg)(z)\sin\theta + mg(0)\sin\theta$$

$$\tau_c = (Mg)(z)\sin\theta$$

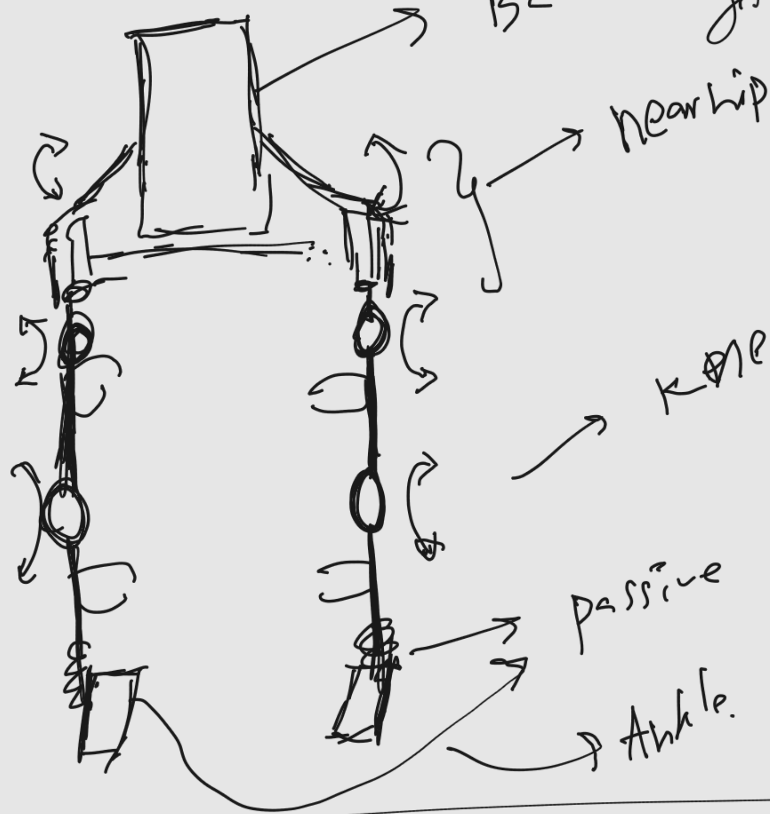
Free body

J_1



$$\tau_2 = \Big[\underbrace{(Mg(z)\sin\theta + mg)}_{\text{Force of weight}} \overset{+wg}{+} \underbrace{eg}_{\text{Exoskeleton weight}} \Big] l_1 \sin\theta$$

Exoskeleton design



$\tau_{body} = W \times d \sin\theta$

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electri-l compo-ts | complete design

* correct torque cal-
  * (conc. Lik. Body weig.)
  * (carrying up)
* Motor selection
* control design
* Overview design

$z \rightarrow$ Horizontal dist from hip joint to box (m)

$z' \rightarrow$ Vertical distance from hip joint to COM of battery

Hip joint torque (τ_1)

$\tau_{box} = M \cdot g \cdot z (\sin\theta)$ (Torque due to box's weight)

$\tau_{battery} = m \cdot g \cdot z' \cdot \sin\theta$ (Torque due to battery's weight)

$\tau_{exo} = e \cdot l_{hip} / 2$

$\tau_1 = (M \cdot z + m \cdot z') g \sin\theta + e \frac{l_{hip}}{2}$

Assumption: e is supposed to act at midpoint of link b/w hip & knee joint

$l_{hip} \rightarrow$ length of hip joint to knee joint

$l_{knee} \rightarrow$ length of knee joint to ankle

Knee Joint Torque (τ_2)

$\tau_{box} = M \cdot g \cdot l_k \sin\theta$

$\tau_{exo} = \frac{e}{2} \cdot l_{knee} / 2$

Assuming the weight of lower part of exoskeleton is half the weight of exoskeleton

$\tau_2 = Mg \cdot l_k \sin\theta + \frac{e}{2} l_k / 2$

$$\tau_2 = M_g \cdot l_k \sin\theta + \frac{e}{4} l_k$$

$$\tau_2 = l_k \left(M_g \sin\theta + \frac{e}{4} \right)$$

for thigh $l_{kn} = 46\,cm$ (model A)

$l_k = 40\,cm$

$\tau_1 \quad \theta = \{-30, 50\}$

$\tau_2, \theta = \{0, -40\}$

2t

Torque Calculation :

Thigh Joint :

$$\tau_1 = (M.z + m.z')g \sin\theta + \frac{el}{2}$$

hand distance

$Z = 76 \Rightarrow 0.76$ $l_h = 46 \Rightarrow 0.46$

$Z' = 35 \Rightarrow 0.35$ $M = 20kg$

$m = 4kg$

$e = 10kg$

$$\tau_1 = (20 \cdot 0.76 + 4 \cdot 0.35) \times 9.81 \sin\theta + 10\,\frac{0.46}{2}$$

$$\tau_1 = (15.2 + 2.44)\, 9.81 \sin\theta + 2.3$$

(a) $\theta = \{-30, 50\}$

$$\left.\begin{aligned} \tau_1 &= -86.52 + 2.3 = -79.123 \\ &= 127.05 \end{aligned}\right\} \begin{aligned} &\theta = -30^\circ \\ &\theta = 50^\circ \end{aligned}$$

-0.5

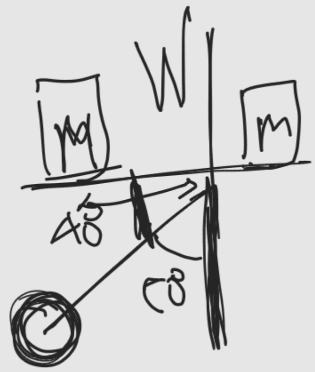
-4.905

$$\underline{\tau_2 = l_k \left(Mg \sin\theta + \frac{e}{4} \right)}$$

$$= 0.40 (20 \times 9.81 \sin\theta + 2.5)$$

$\theta = \{0^\circ, -40^\circ\}$

$$\left.\begin{aligned} \tau_2 &= -123.068\,\text{Nm} \\ &\ \ 2.5\,\text{Nm} \end{aligned}\right\} \begin{aligned} &\theta = -40^\circ \\ &\theta = 0^\circ \end{aligned}$$



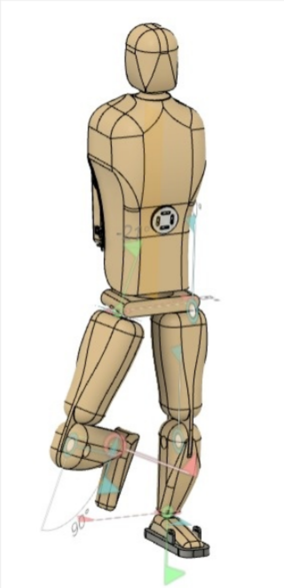
$$\tau_2 = 1017.57 \quad \left.\right\} \begin{aligned} &50 \\ &-30 \end{aligned}$$

$$eg + Mg(z)\sin\theta + mg + Wg$$

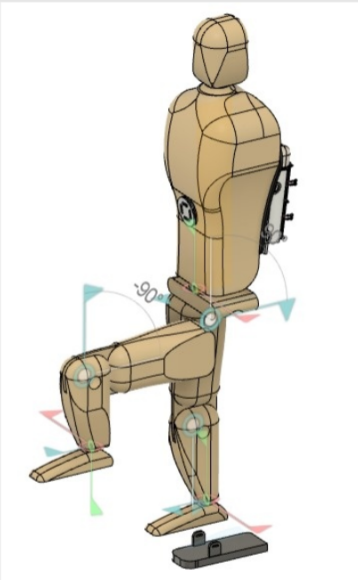
$$M(z)\sin\theta +$$

$$\left(20(0.76)\sin\theta + 10 + 4 + 80\right)g$$

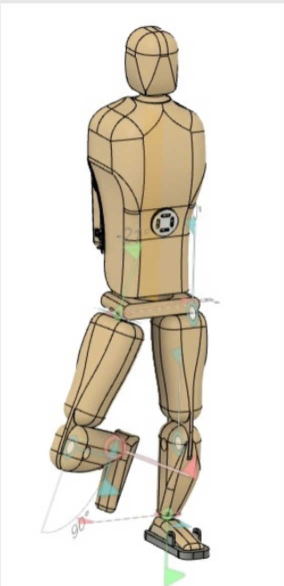
$$\left(20(0.76)^{\times 0.64} + 10 + 4 + 80\right)g.$$



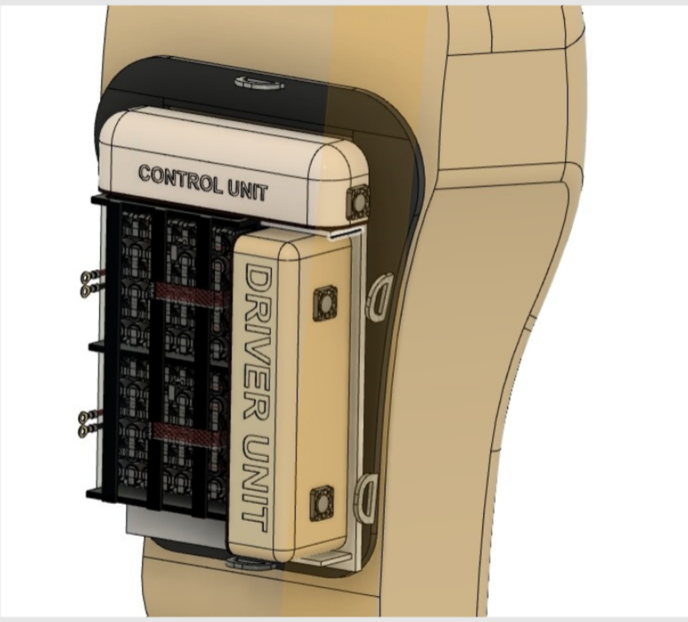
Model of a Human Body with a height of approximately 185 cm, has been created and the required joints have been made.



To aid with the ergonomic calculations the knee and thigh joints have been constrained to assemble actual human motion.

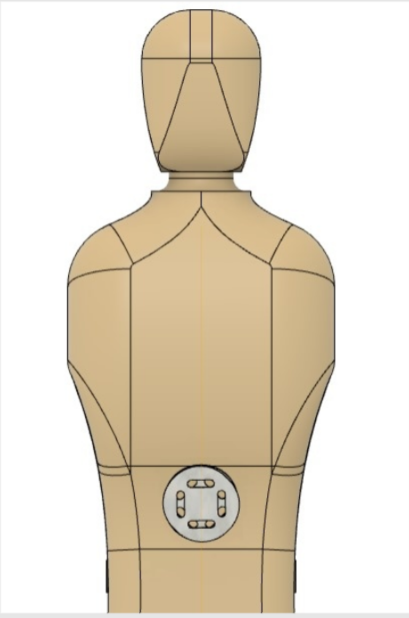


In all appropriate places, ball joints have been used.

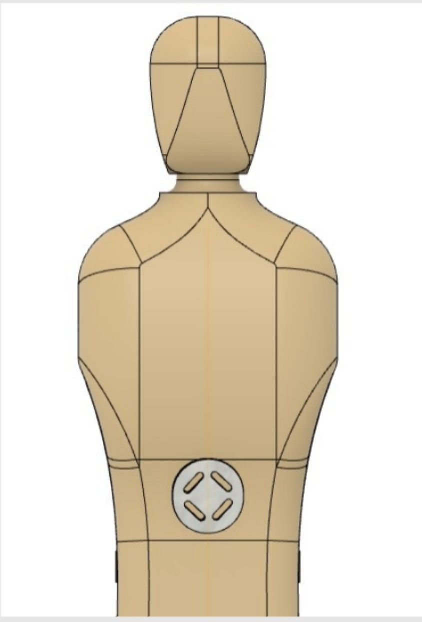


Using 2, 1800 mAh 22.2V Li-Po batteries, which can be extended to 3-4 batteries to run for 8 hours.

We are planning to use Brushed 12V DC motors in conjunction with stepdown converters.



For the release mechanism of the belts that bind the torso part of exoskeleton to the body, two discs joined by a ball bearing are used.



The discs have 4 slots in them to lock in the respective belts. The top disc is rotated by the user to misalign the slots to securely lock the belt in place

We are planning to use Harmonic Gearbox . that The reason is that ehrn compared to traditional gearboxes like cycloidal gears, it has high precision and almost little to no backlash , which is crucial in this context .

linear actuator : Specification

- LA 23
- 6 spindle pitch
- 1500 N

Hip joint Torques

@ -30° $\tau_1 = -37.08$ Nm

@ 90° $\tau_2 = 136.80$ Nm

$$\tau_1 = M \cdot g \cdot Z \cdot \sin\theta + e\, g\, \frac{l_{hip}}{2} + W_{upper} \cdot g \cdot D_{upper} \cdot \sin(\theta)$$

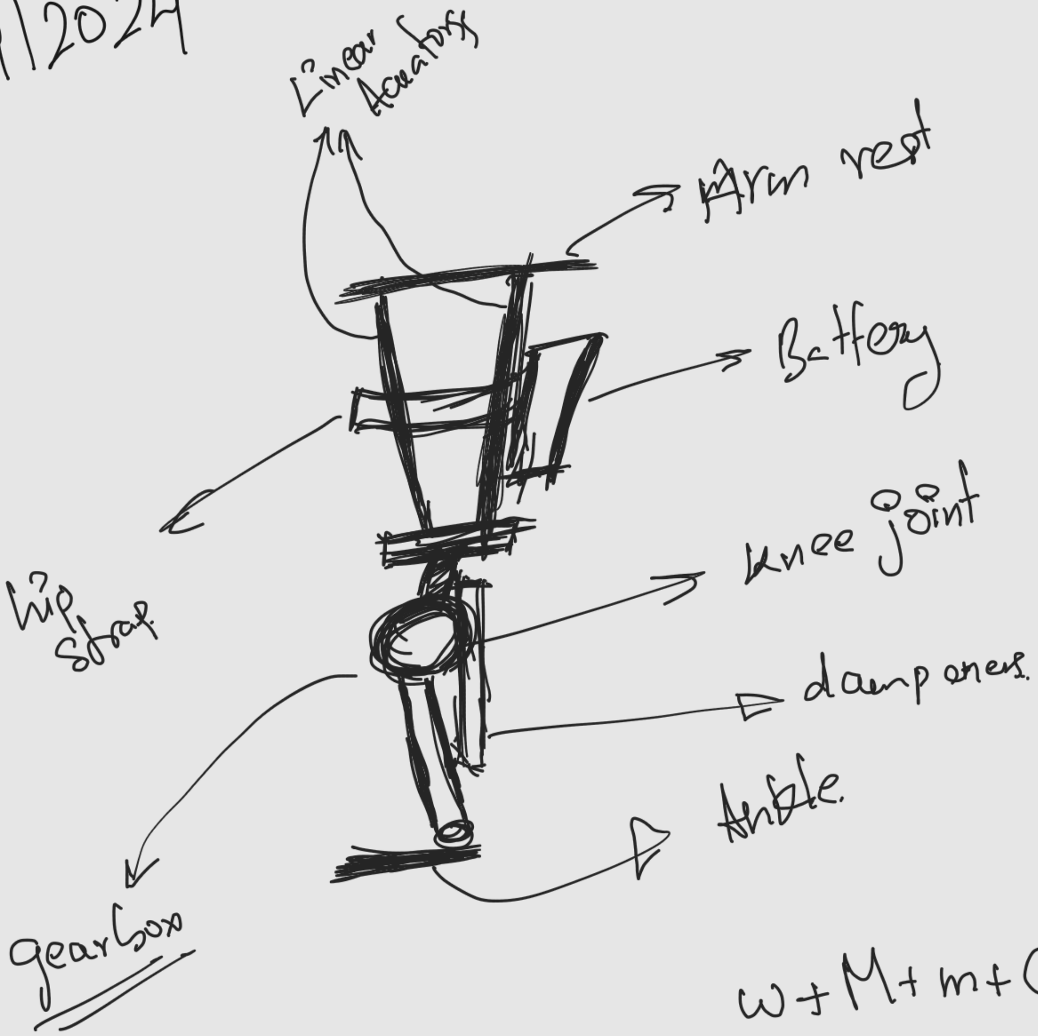
Knee joint torques

@ -43° → -93 Nm

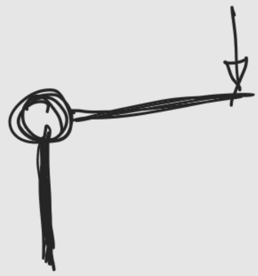
@ 0° → 0 Nm

$$\tau_2 \; M g z \sin\theta + W_{upper} \cdot g \cdot D_{upper} \sin\theta + W_{lower} \cdot g \cdot l_{knee} \sin\theta$$

18/04/2024



$\omega + M + m + C$

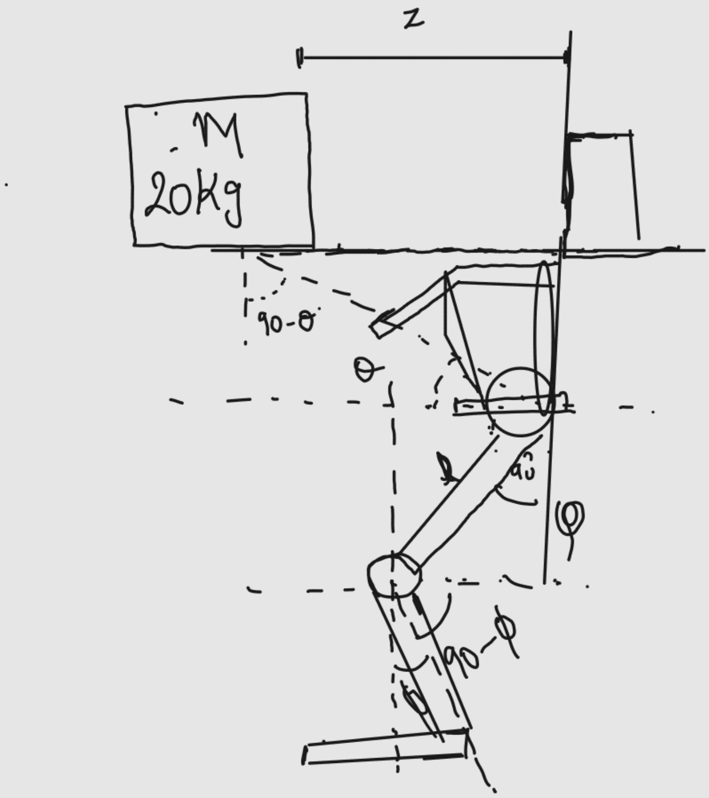


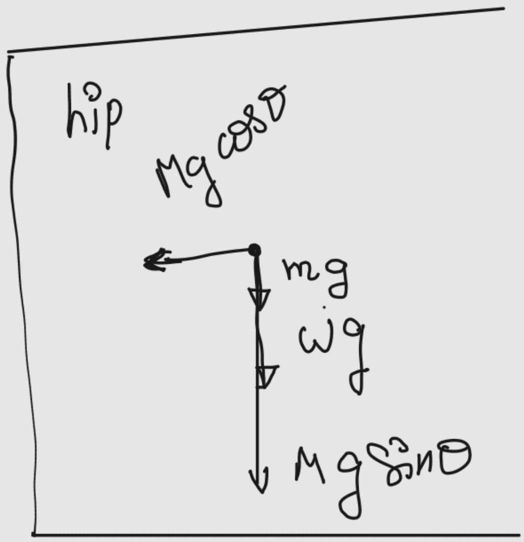
$F_1 = 20 \times 9.8 = 196$

$F_2 = 80 \times 9.8 = 784$

$F_3 = 3 \times 9.8 = 29.4$

$F_4 = 10 \times 9.8 =$





Knee

Descent ⇄ Ascent

M- Weight of the box
m- weight of battery pack
w. weight of human body
Z→ Horizontal distance from hip joint to box
Z' -> Vertical distance from hip joint to COM of battery
e -> Weight of exoskeleton

Assumptions

1. The weight of exoskeleton is evenly distributed
2. The weight of lower part of exoskeleton (below knee) is half of the entire weight.

Hip Joint Torque (τ_1)

$$\tau_{box} = M.g.z.\sin(90-\theta) + M.g.\,l_{hip}\sin\theta$$
$$= M.g.z\cos\theta + M.g.\,l_{hip}\sin\theta$$

$$\tau_c = c.g.\left(\frac{l_{hip}}{2}\sin(\theta)\right)$$

$$\tau_1 = \tau_{box} + \tau_{battery} + \tau_c = M.g(z\cos\theta + l_{hip}\sin\theta) + c.g\left(\frac{l_{hip}}{2}\sin(\theta)\right)$$

For knee joints $-30^\circ \leq \theta \leq 50^\circ$

$z' = 0.35\,m$
$z = 0.76\,m$
$l_h = 0.46\,m$
$M = 20\,kg$
$m = 4\,kg$
$c = 20\,kg$

$\theta = 50^\circ$ (Descent)
$\tau_1 = 95.84 + 0.35 + 34.56 = 130.75\,Nm$

$\theta = -30^\circ$ (Ascent)
$\tau_1\ 64.56 + (-0.23) + (-22.563) \Rightarrow 41.77\,Nm$

Knee Joint Torque (τ_2)

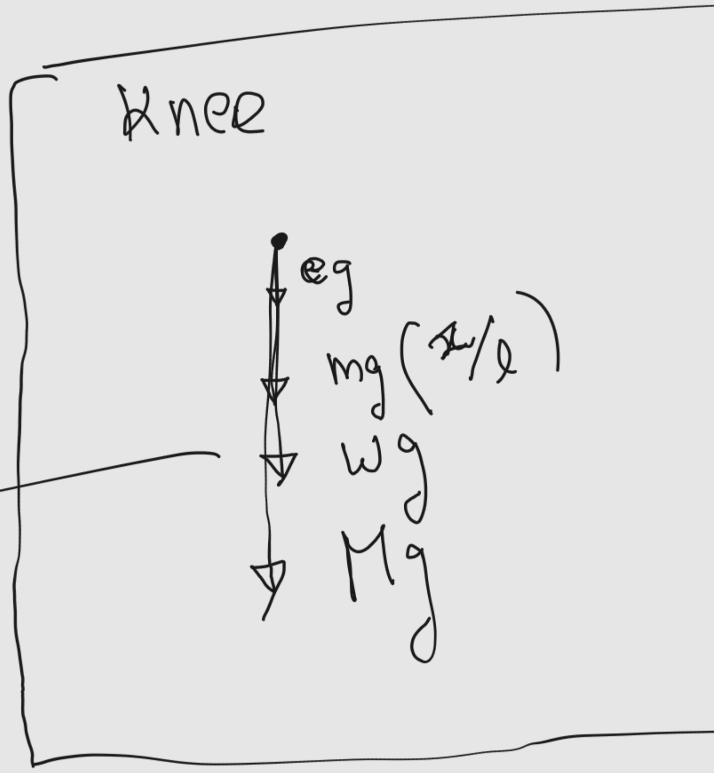
τ influenced by exoskeleton below the knee → During descent

$$\tau_2 = \frac{e}{2} \cdot g \cdot \left(\frac{l_{knee}}{2} \sin(\theta) \right)$$

$-40° \leq \theta \leq 0°$

$\tau_2 = -12.611$ Nm

knee-is directly above the weigth.



Since we have to limit the weight using Li-ion is not feasable, hence LiPo is more of a better solution, hence

For running the entire setup, the Batteries used for the System is 4 6s Lipo batteries with 10 Ah Capacity and a discharge rate of 35 C.

Total power consumption:

→ Each linear actuators consume 7.4A at 12V.

$$\therefore \quad P = V \times I$$

$$P = 12 \times 7.4$$

$$= 88.8 \text{ Watts}.$$

For total of 8 actuators:

$$P = 8 \times 88.8$$

$$\boxed{P = 710.4 \text{ watts}}$$

Battery configuration & Total capacity:

$$\text{Total capacity} = 4 \times 10\,000$$

$$= 40 \text{ Ah}$$

Energy Avalabity of Battery:

$$E = V \times capacity$$

$$E = 22.2 \times 40$$

$$= 888\ wh$$

Effective energy =

$$888\ wh \times 0.95 = 843.6\ wh$$

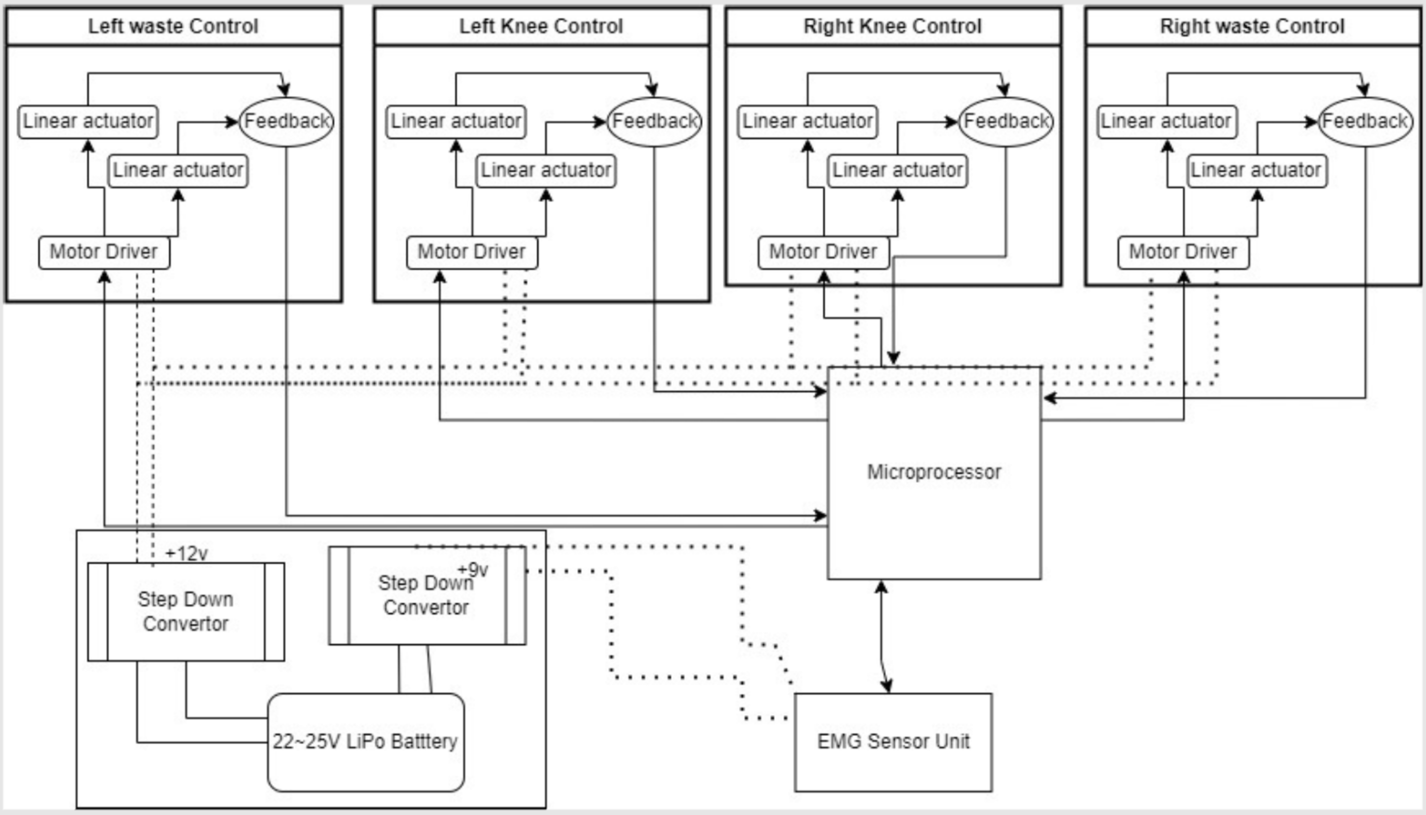
Expected Runtime:

$$R = \frac{\text{Effective Energy}}{\text{Total power}}$$

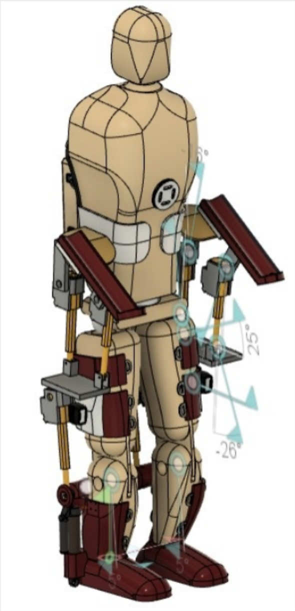
$$= \frac{843.64\ wh}{710.4\ W}$$

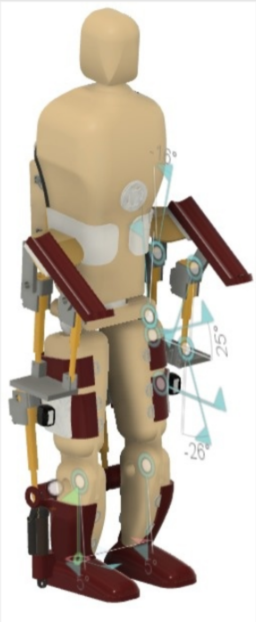
$$= 1.188\ h$$

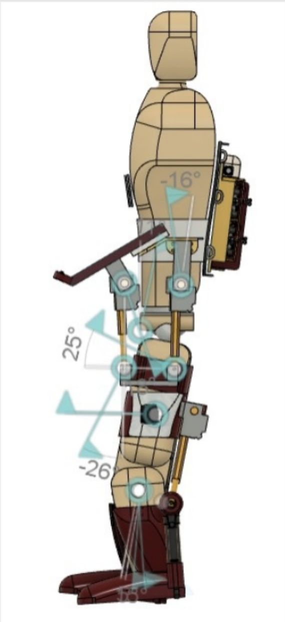
Schematic diagram of the Exoskeleton and the components.

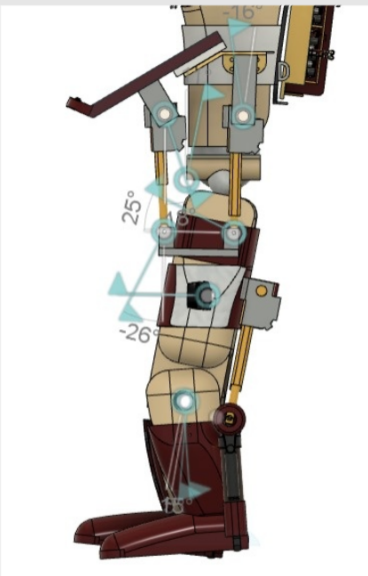
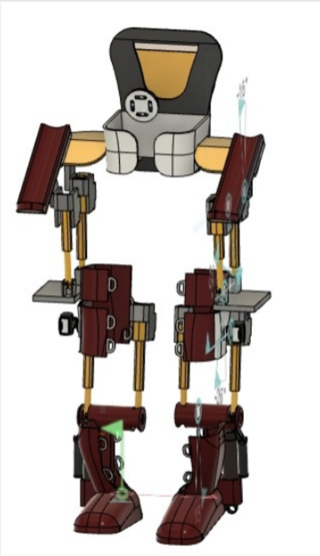
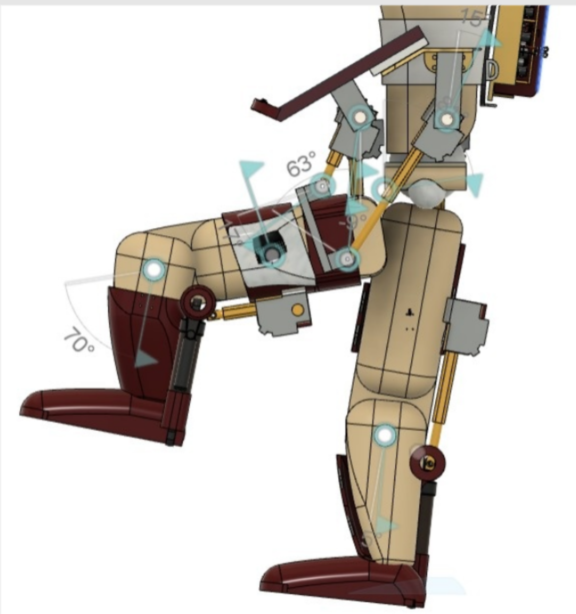


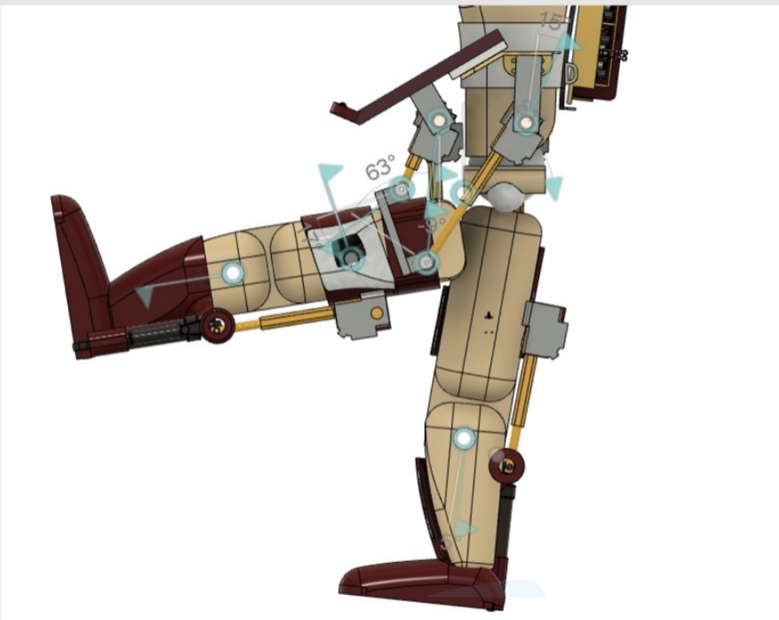
- ☆ LINAK LA23 Linear Actuators are being used
- ☆ 300W 10A DC-DC Stepdown buck converter
- ☆ SmartAlex DC motor Driver.
- ☆ Raspberri PI 5.

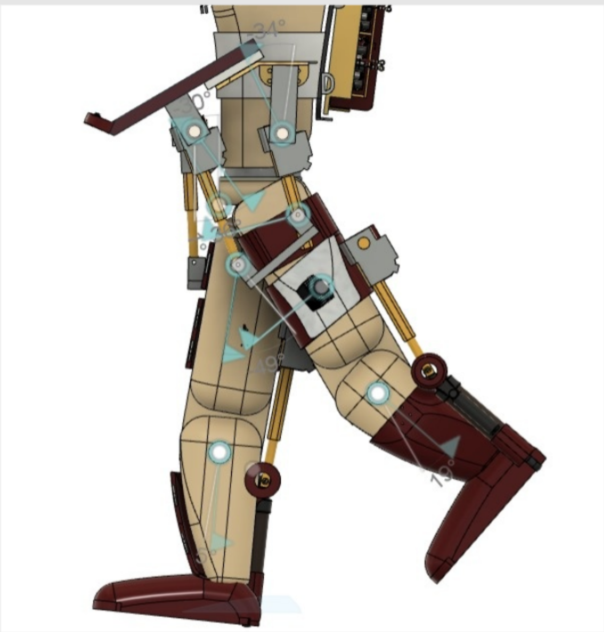

25°
-26°

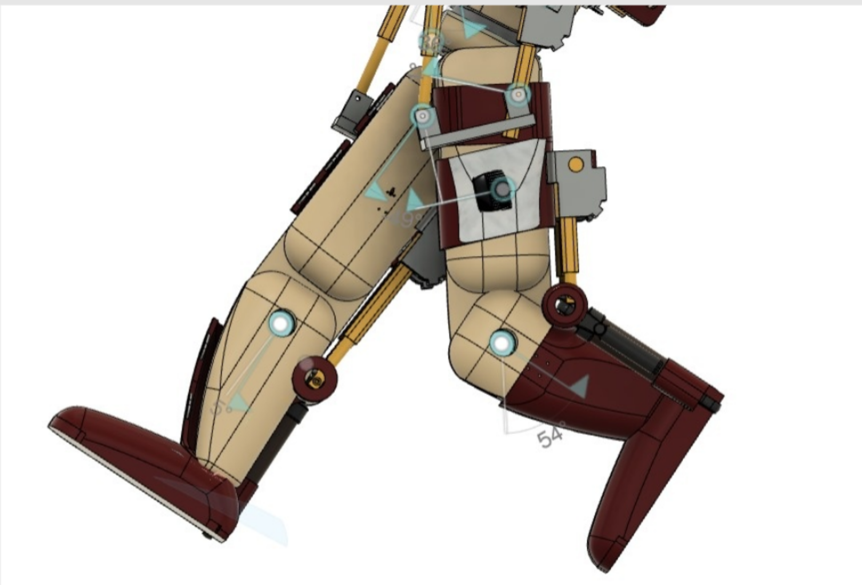

25°
-26°

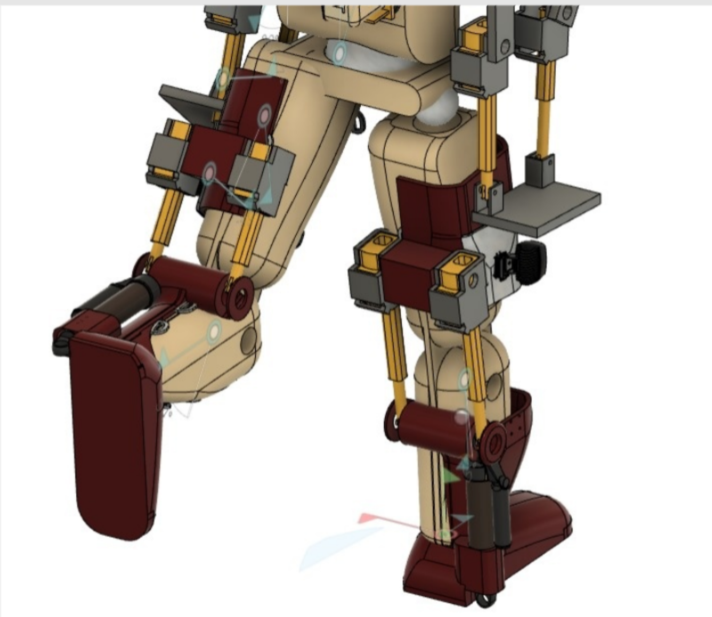

-16°
25°
-26°

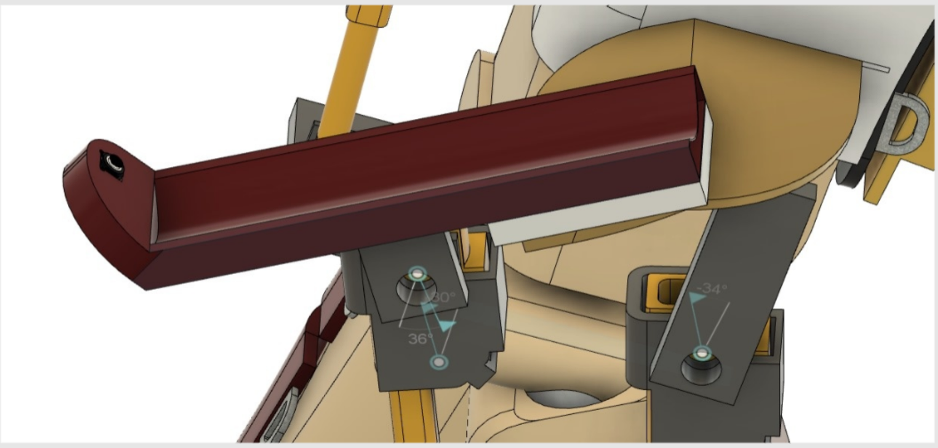

-16°
25°
-26°


15°
63°
70°

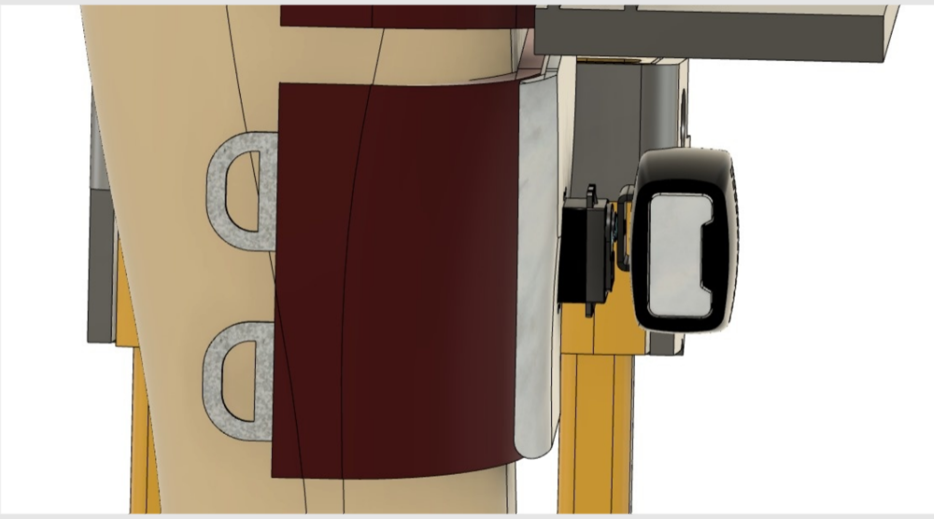

63°

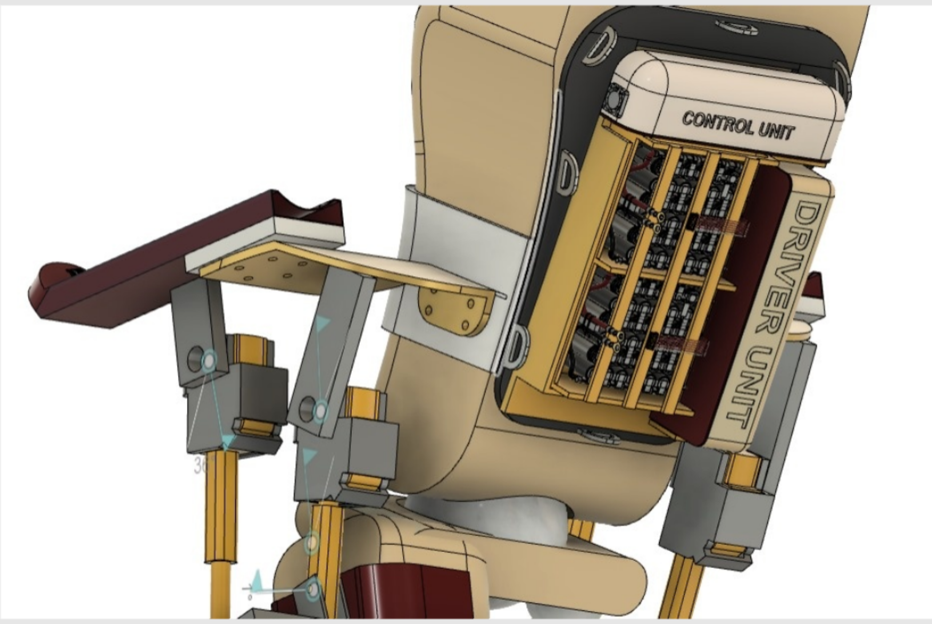

34°
13°

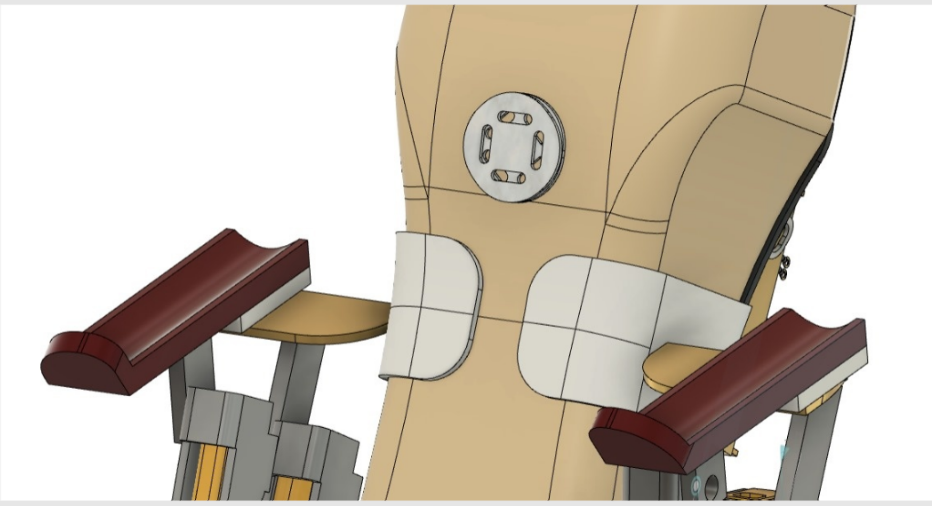

54°

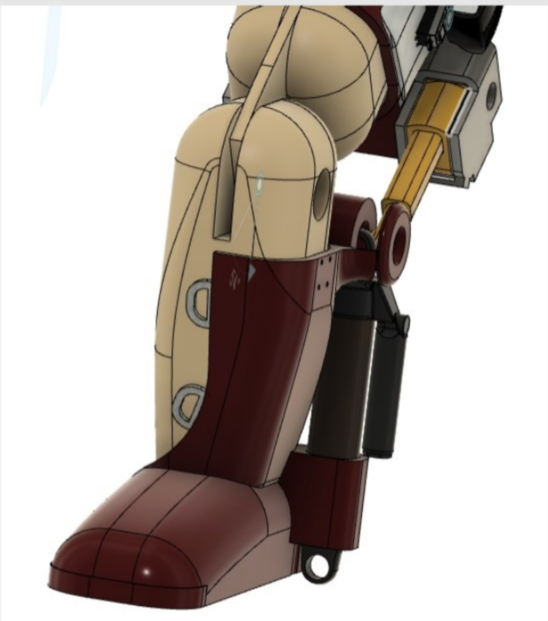



30°
36°
-34°









This is our lower exoskeleton desgin.

The system consist of 8 Linear Acutators without any gearbox system.

it supports humans weigth upto 80kgs and the person in the exosekeleton can lift upto 20kgs.

The unique desgin has hand holder stand were the user and place their hand while moving.

hip joint is controlled via totally 4 linear actuators, 2 per each joint.

the forward facing actuator will pull the thigh while we lift the leg and back face actuator will push the thigh. the same thing happens vice-versa.

thetwo linear actuators are connected below knee . While we knee joint is bent , the actuators will pull on the shoes .

The Knee joint has a limit of -40 to 0 and the hip joint has a limit of -30 to 50 (in degrees)

The ankle is connected to a dampening rod , which will transfer the weight from the joints smoothly into the ground .

The battery pack and the arm holder are connected to waist using a belt , from where the linear actuators are used to connect the torso to thigh

The exoskleton weight after fitting all the motors is roughly estimated to be around 20kg - 25 kg . It is a very modular design and does not have any gearbox systems

Walking mechanism - The linear actuators allowed exoskleton to move in various different directions and allowing more degrees of freedom.Due to high torque capacity and faster moving speed this mechanism is perfectly suitable for longer distances while carrying a load

As a additional feature we have added light systems near the thigh regions. The light systems are similar to fog lights found in vehicles .It can be useful while manuevering different terrains.

We have also added joystick control for this light systems in order to be able to tilt the light system in different angles . We have placed this joystick in the thumb area of armrest to enable the users to efficiently use this .We chose the design with armrest because we can add a lot of toher new features in the future as further improvements .

The half boot design features a cutout towards the right hand side of the boot to slide in and out the foot with ease , with adequate straps to prevent loosening . The boot also houses a dampener that extends when a load is lifted and when the sole is flat on the ground again, the dampening motion smoothens the returing motion .