Development of a Tree Climbing Snake Robot

Design Presentation I

Team 10

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Problem Definition

- Unstable trees may fall at any moment
- Removing tall trees should be done by professionals
  - Requires specific skills and precision
  - 200 tree-related fatal injuries every year
- Homeowner’s insurance
  - $500-$1,000 for removing fallen trees
  - Healthy vs. Dead trees

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Tree Removal Services

- Removing Process:
  - De-limbing on the way up
  - Cutting small segments on way down
  - Cut at base once at controllable height
- Price ranges from $150-$2,000
  - Complexity of job
  - Height of tree
- Focus on pine trees
  - Average Diameter: ~2 ft
  - Height: Up to 100 ft
  - Shape: Round and straight

Project Goal Statement

Scope:

- To climb a branchless tree, in a helical manner, carrying a payload for future iterations.

Goal Statement:

- Build a remotely operated snake-like robot that will safely climb trees.

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Project Goal Statement

Objectives:

- Ascend and descend a tree while satisfying the following:
  - Tree diameter of at least 10 in
  - Climb in a helical (spiral) path
  - Ascend at a speed of at least 1 ft/min
  - Hold up at least 10 lb
  - Attach camera to provide feedback

Stretch Goals:

- Obtain a minimum payload of 20 lb
- Implement deployable stability arm

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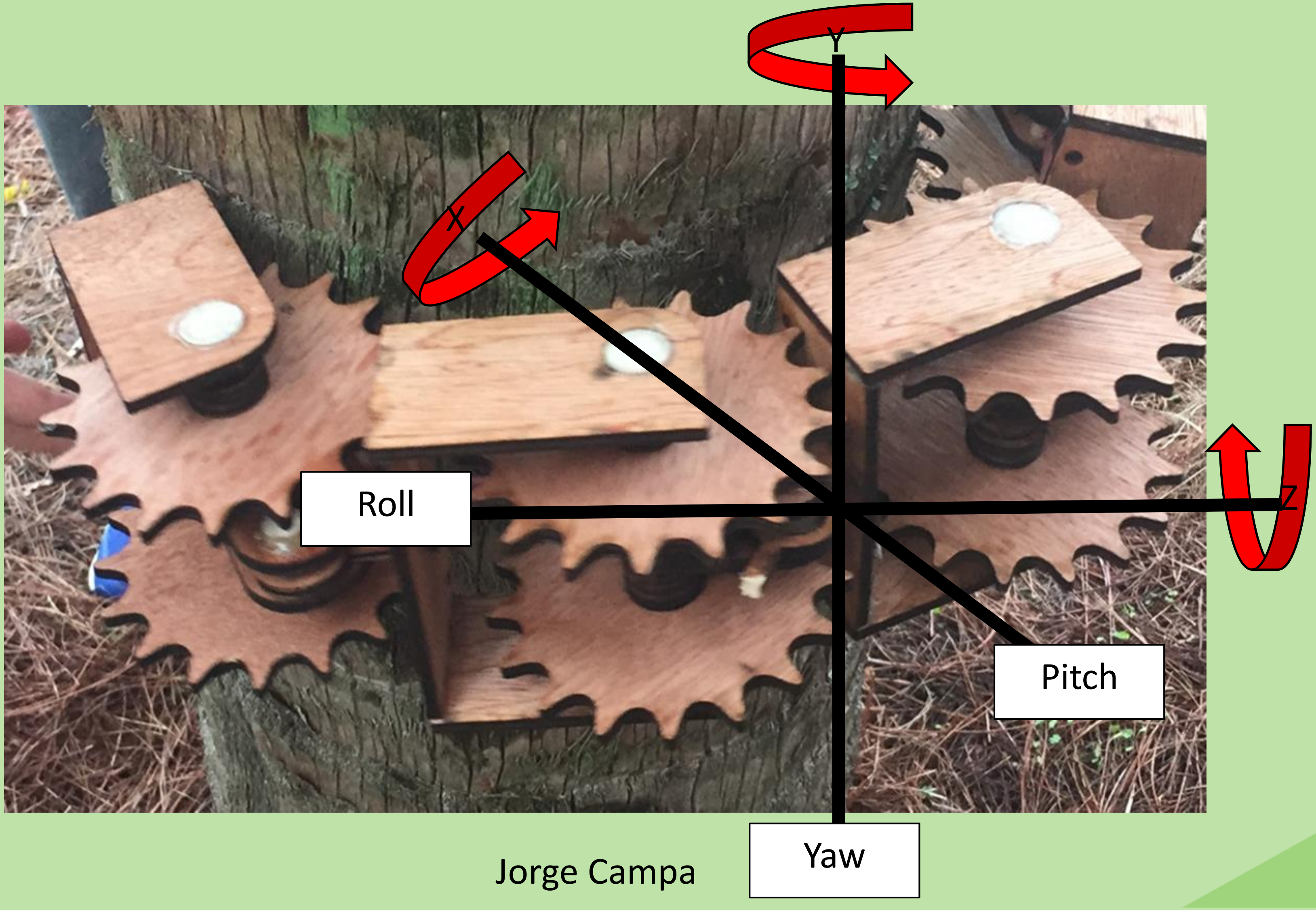
Motion Concept



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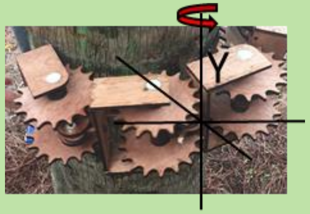
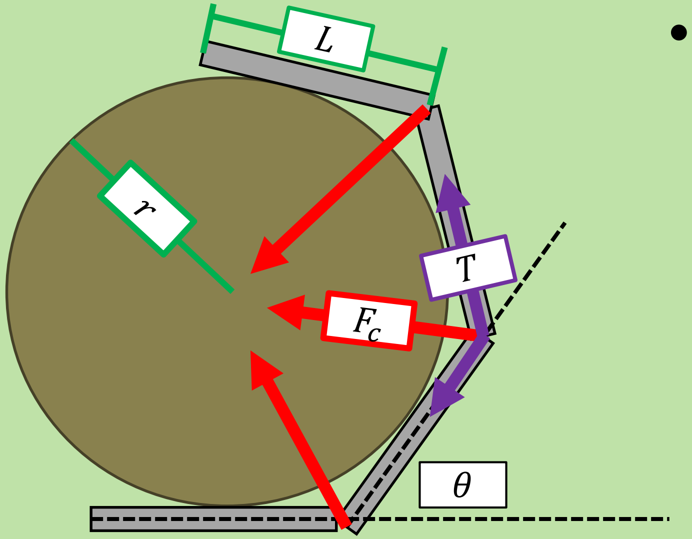
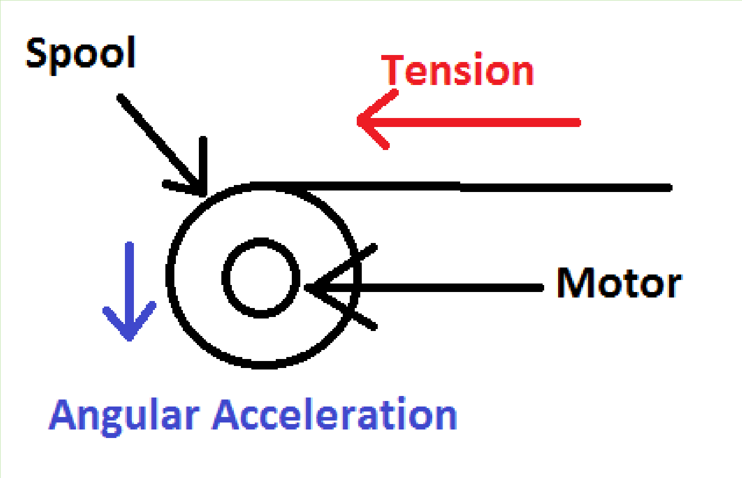


Clamping Analysis





- Assumptions:
  - Tension (T) is constant
  - Module-to-module angle change (θ) is constant
  - Clamping is independent of helix
  - No losses due to friction

Final torque needed for clamping ≈ 20 $lbf \cdot ft$

$$\theta = 2\tan^{-1}\left(\frac{L}{2r}\right)$$

θ is the module-to-module angle
L is the length of the module
r is the radius of the tree

$$F_c = T\sqrt{2 - 2cos\theta}$$

F_c is the clamping
T is the tension

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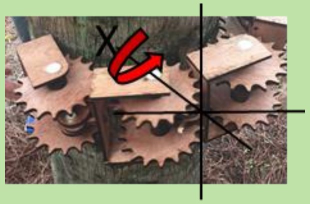
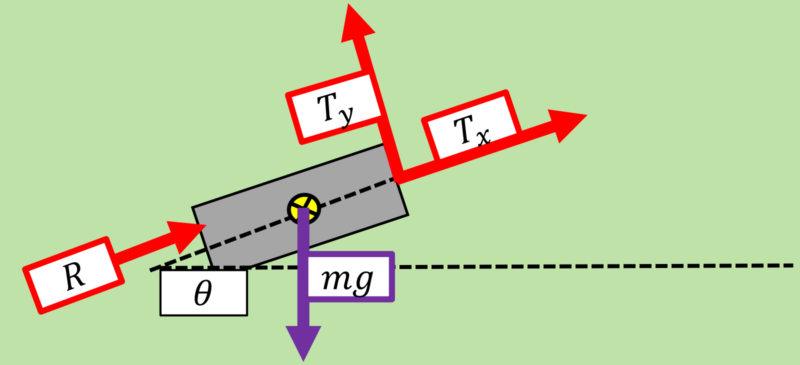


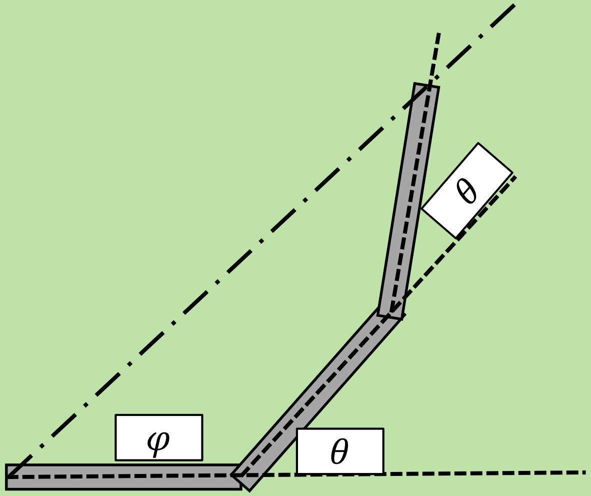
Helix Analysis

- Assumptions:
  - Module-to-module angle change (θ) is constant
  - Helix is independent of clamping
  - No losses due to friction

Final torque needed for helix ≈ 20 $lbf \cdot ft$

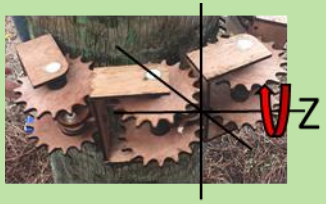


$$\begin{bmatrix} cos\theta & cos\theta & sin\theta \\ sin\theta & sin\theta & -cos\theta \\ -2h & 0 & 0 \end{bmatrix} \begin{bmatrix} R \\ T_x \\ T_y \end{bmatrix} = \begin{bmatrix} 0 \\ mg \\ -\frac{mg}{2}(Lcos\theta + hsin\theta) \end{bmatrix}$$



$$\varphi = \frac{\alpha}{2} + 90 - \sin^{-1}\left(\frac{\sin(n\alpha)}{\sqrt{2-2\cos(n\alpha)}}\right)$$

φ is the total pitch angle
α is the module-to-module angle
n is the number of modules
L is the length of the module
h is the height for reaction force
R is the reaction force between modules



Wheel Orientation

- Assumptions:
    - Pivot point at wheel
    - Clamping force is always directed towards the tree
    - Helix generation forces are negligible for orientation

Final torque needed for orientation ≈ 10 $lbf \cdot ft$

$$\sum M_c = F_c * d_1 - N_{1,2} * (d_1 + d_2) - mg * d_0$$

$$F_c = \frac{N_1(d_1 + d_2) + mg * d_0}{d_1}$$

M_c moments about the pivot point

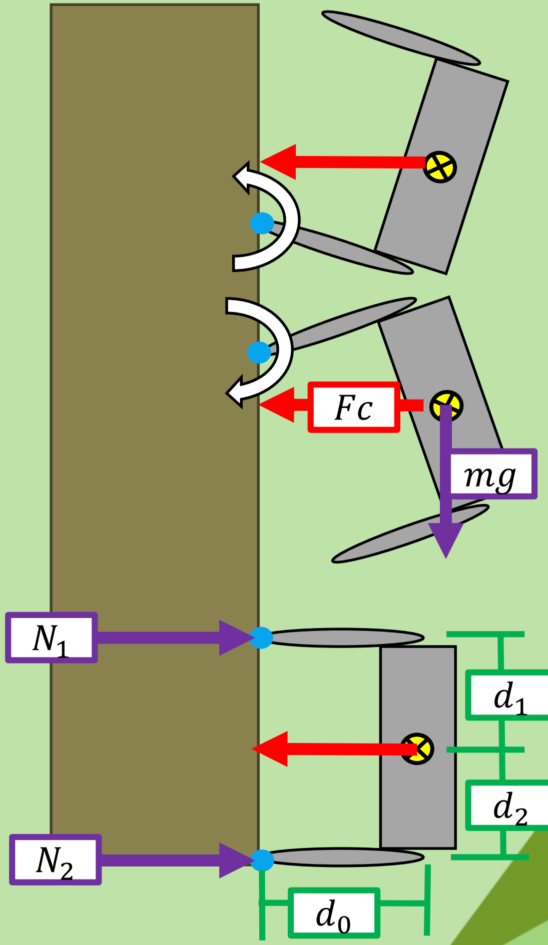
F_c clamping force about Center of Gravity (CoG)

- F_c needs to be *at least* the calculated value

$N_{1,2}$ reactive forces on pivot point (1 or 2, if applicable)

d_0 horizontal distance from CoG to pivot point

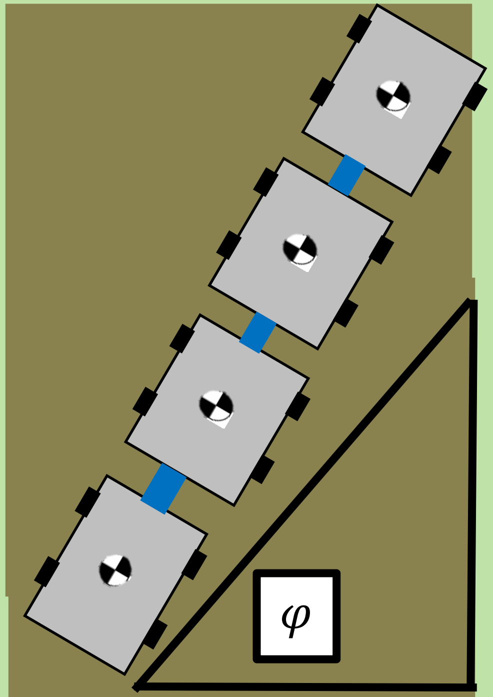
$d_{1,2}$ vertical distance from CoG to pivot point



Wheel motor selection

Assumptions:

- Pitch Angle is constant
- Speed in each wheel is constant
- Climbing speed is $1\ \frac{\text{ft}}{\text{s}}$
- No slip condition is met

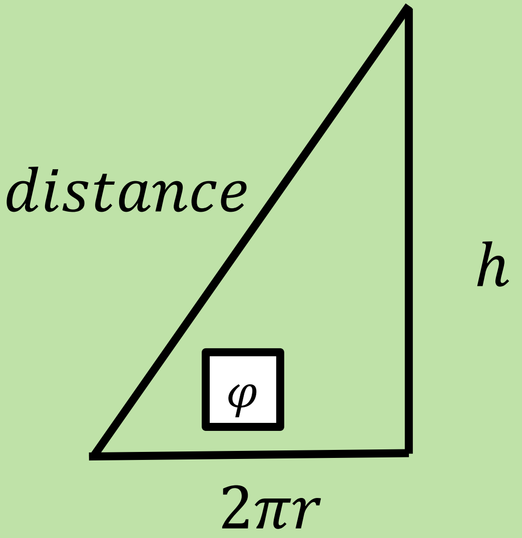


$$\sin(\varphi) = \frac{h}{distance}$$

$$distance = \frac{h}{\sin(\varphi)}$$

$$velocity = \frac{\dot{h}}{\sin(\varphi)}$$

$$\boxed{\omega = \frac{\dot{h}}{r\sin(\varphi)} = 51 \text{ rpm}}$$



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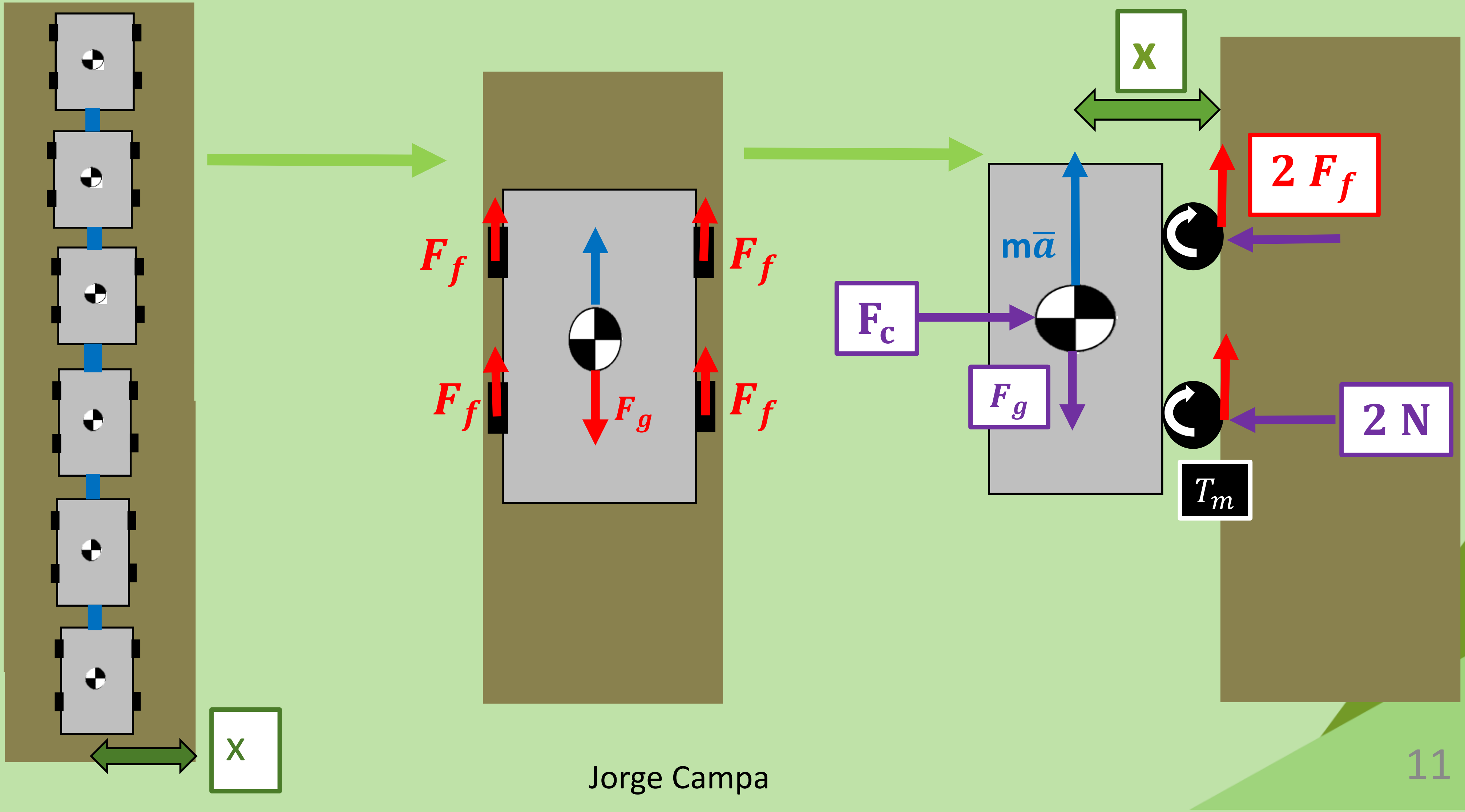
Wheel motor selection



Wheel motor selection

Assumptions:

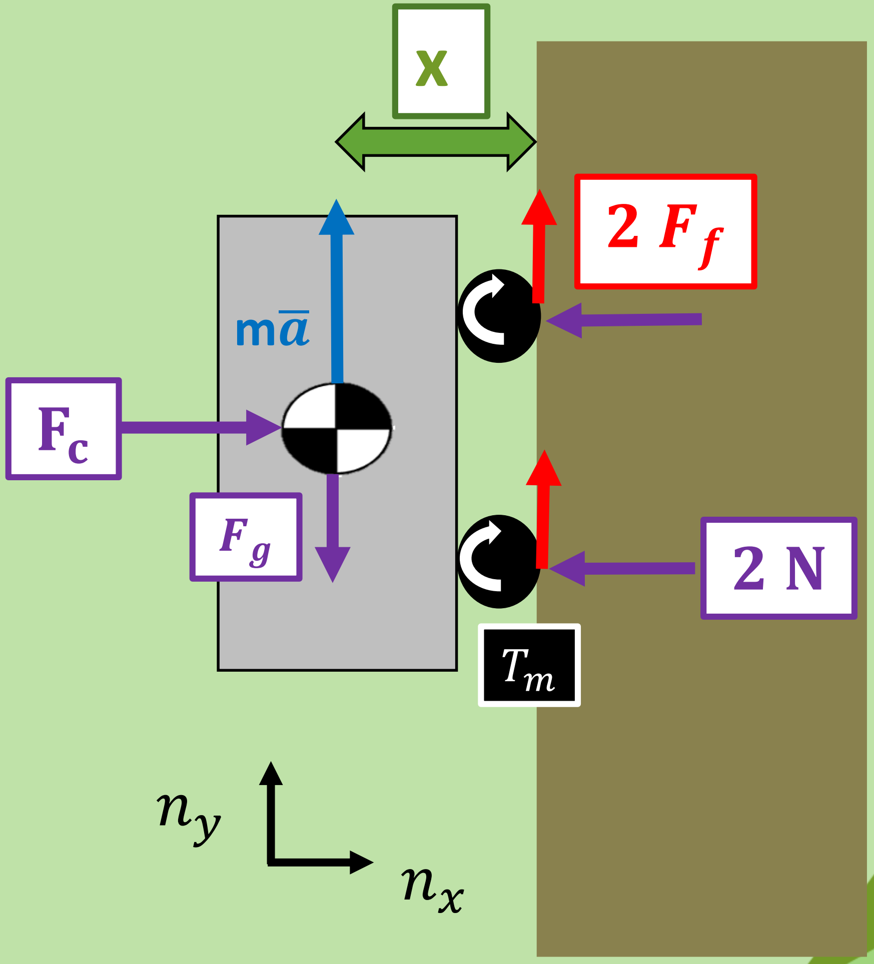
- No slip condition is met
- Force of friction is equal on all tires
- Normal force is equal on all tires

$$Ax = b$$

$$x = A^{-1}b$$

$$\begin{bmatrix} F_x \\ F_y \\ M_z \end{bmatrix} = \begin{bmatrix} F_c \\ m(a+g) \\ 0 \end{bmatrix} = \begin{bmatrix} 0 & 4 & 0 \\ 4 & 0 & 0 \\ 4 & 0 & \boxed{-2} \end{bmatrix} \begin{bmatrix} F_f \\ N \\ \boxed{T_m} \end{bmatrix}$$

$$\begin{bmatrix} F_f \\ N \\ T_m \end{bmatrix} = \begin{bmatrix} 90.2\ lbf \\ 0.185\ lbf \\ 30.1\ lbf \cdot ft \end{bmatrix}$$



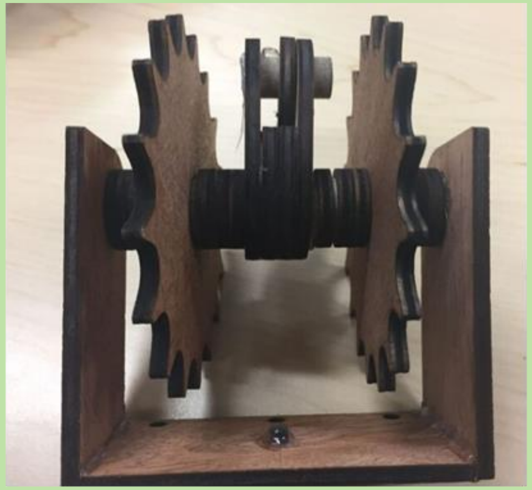
Selected Motors

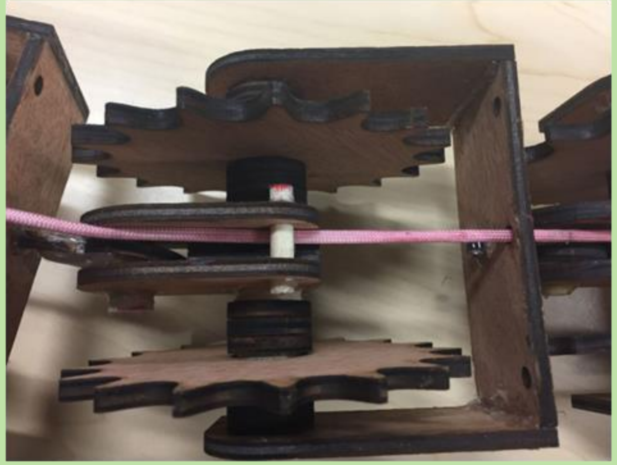
	Clamping	Helix
Calculated Torque	$20\ lbf \cdot ft$	$20\ lbf \cdot ft$
Motor stall torque	$74\ lbf \cdot ft$	$74\ lbf \cdot ft$
Motor max speed	$0.23\ rpm$	$0.23\ rpm$

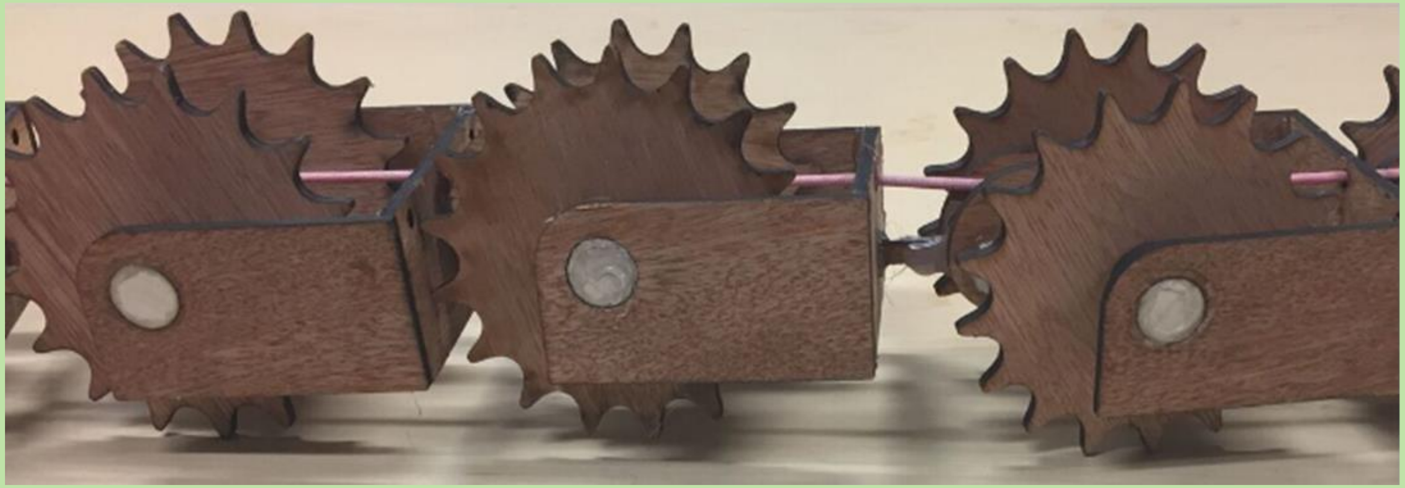
Motor Selected:

- DC motor
- 12 V
- 90 mA
- Gear Ratio- 100:1 (included in data shown)

Current Design – 1st Iteration







Design Limitations

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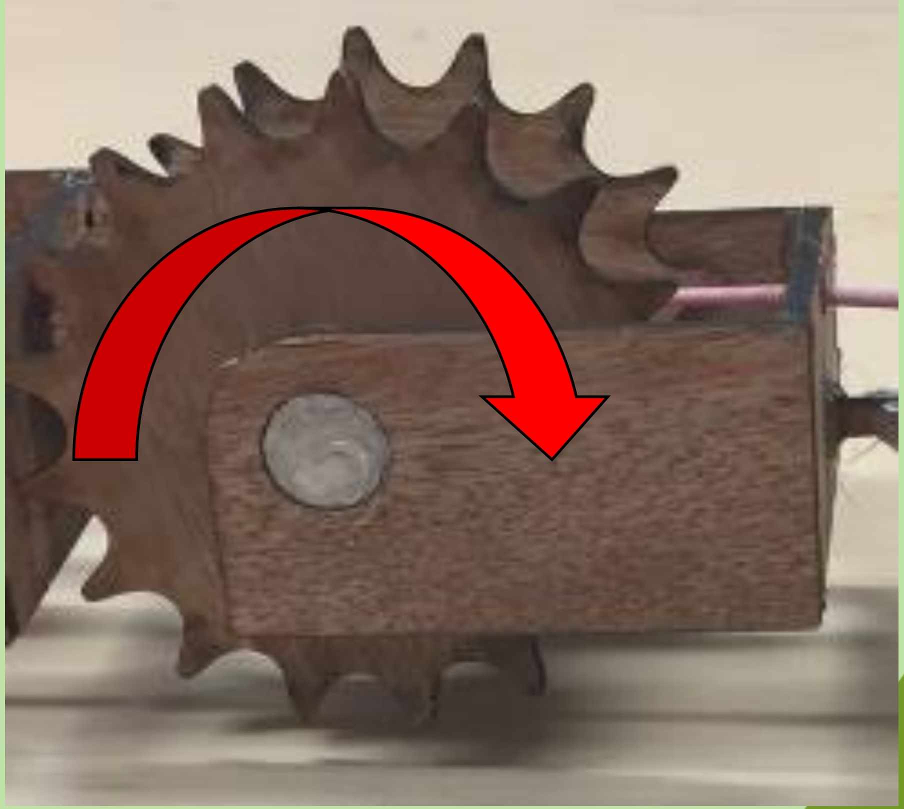
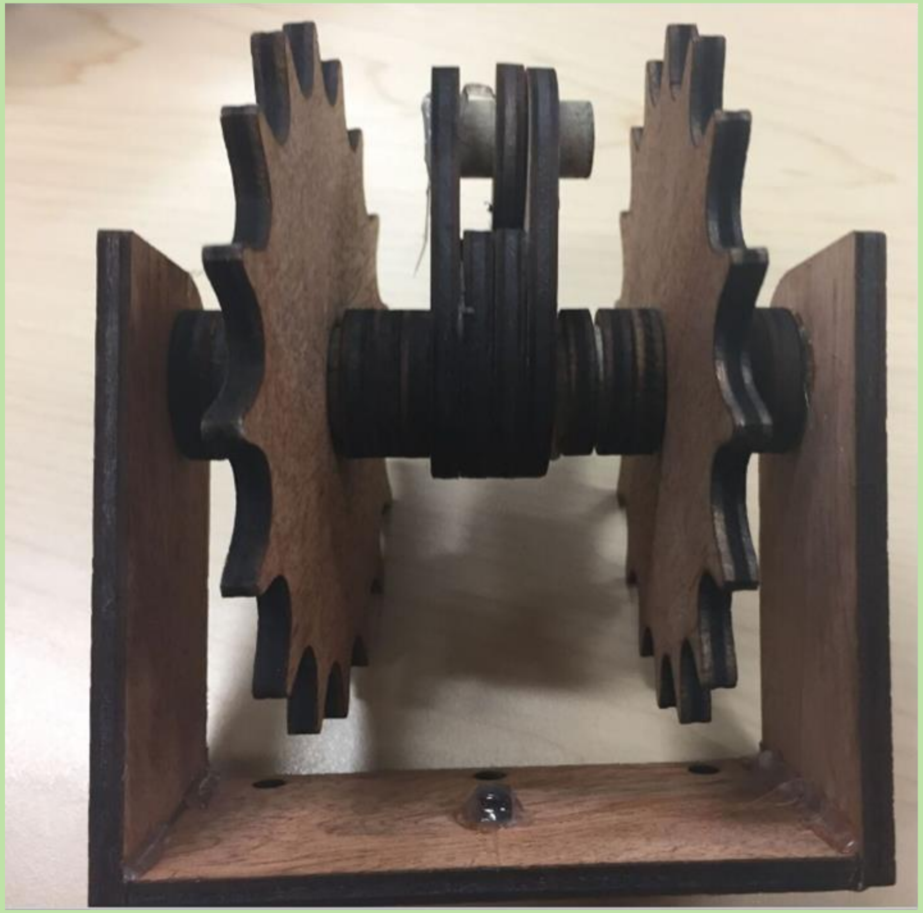


Design Limitations



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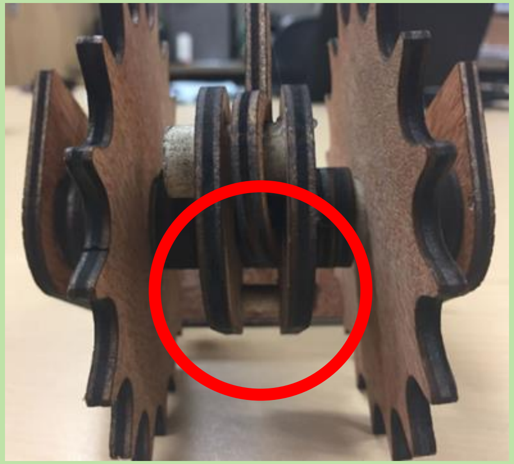
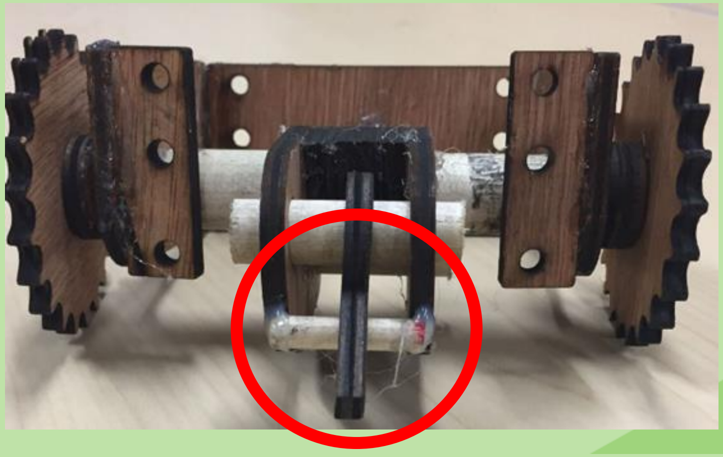
2nd Iteration– Body Module





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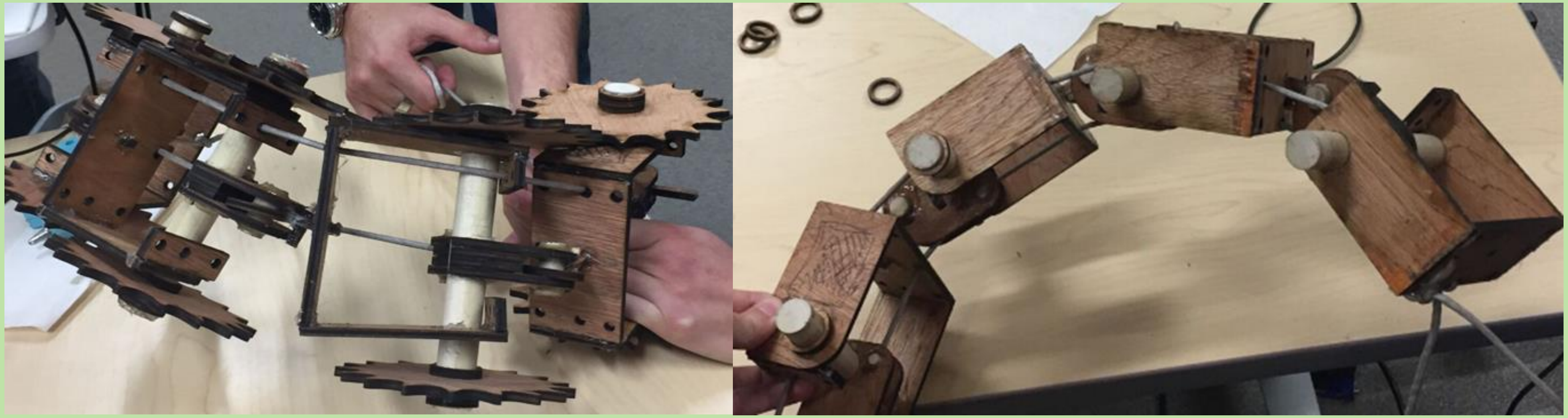
2nd Iteration – Body Module



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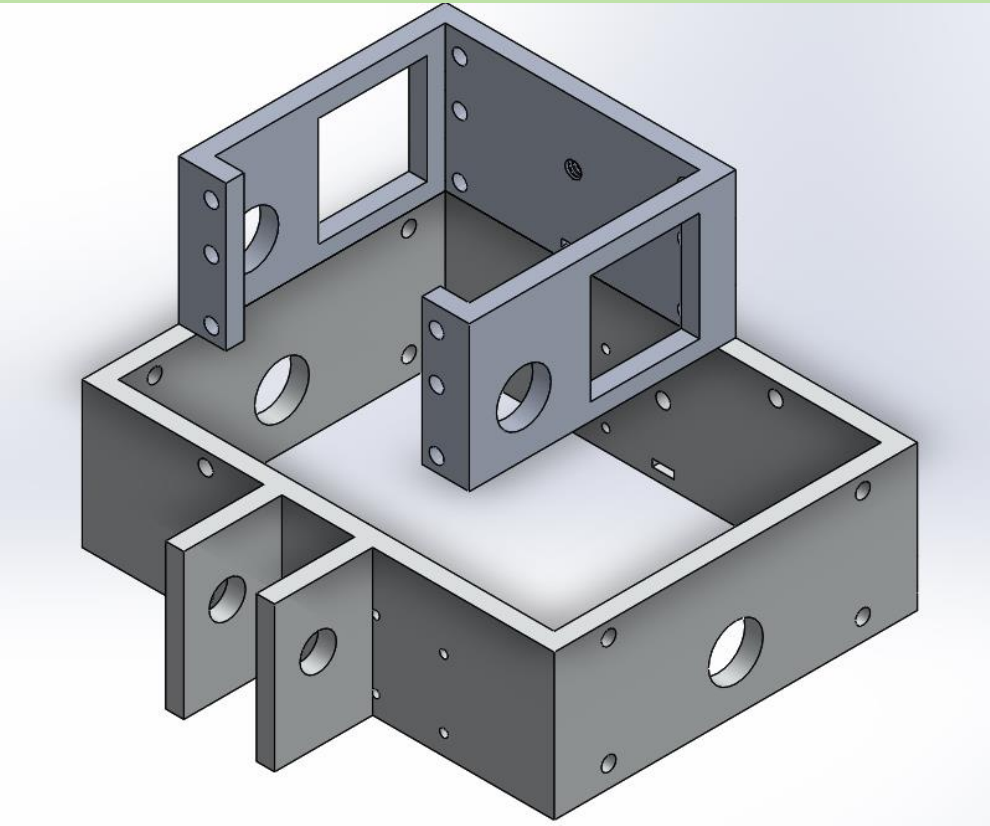
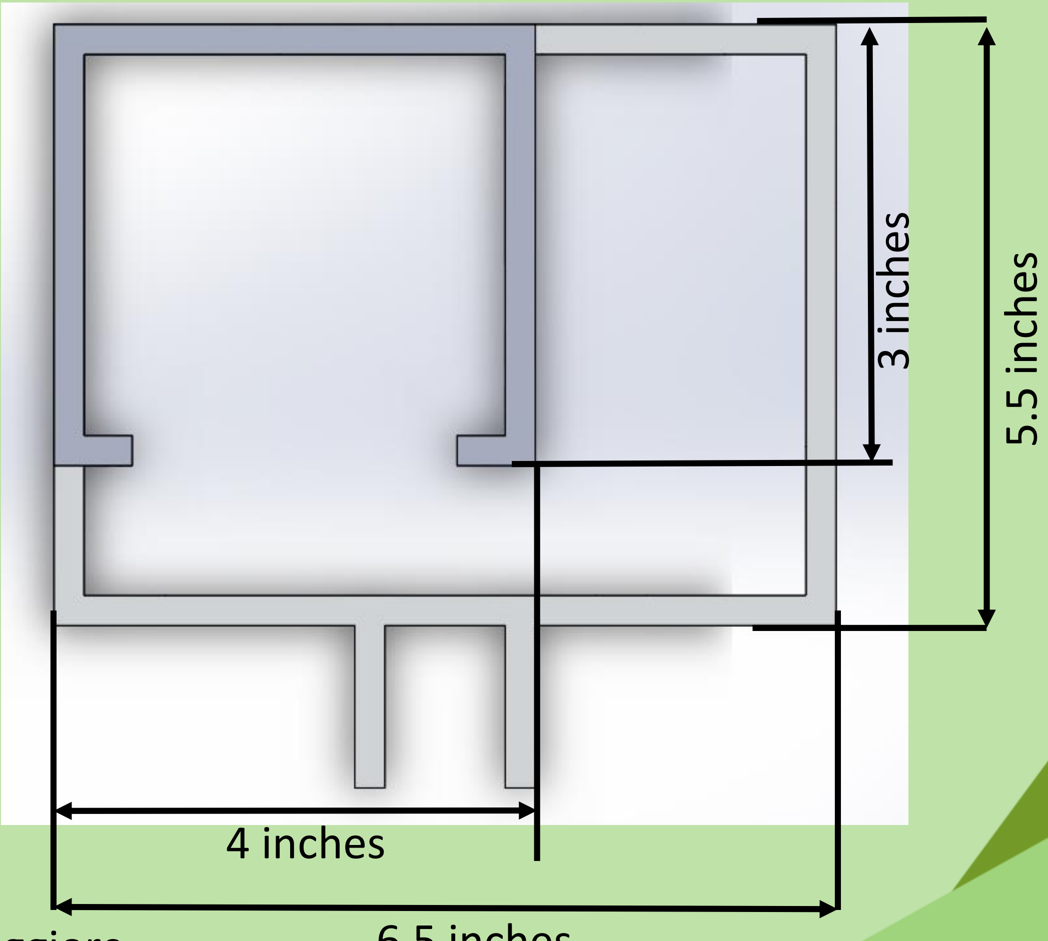
2nd Iteration – Motor Module <Head and Tail>





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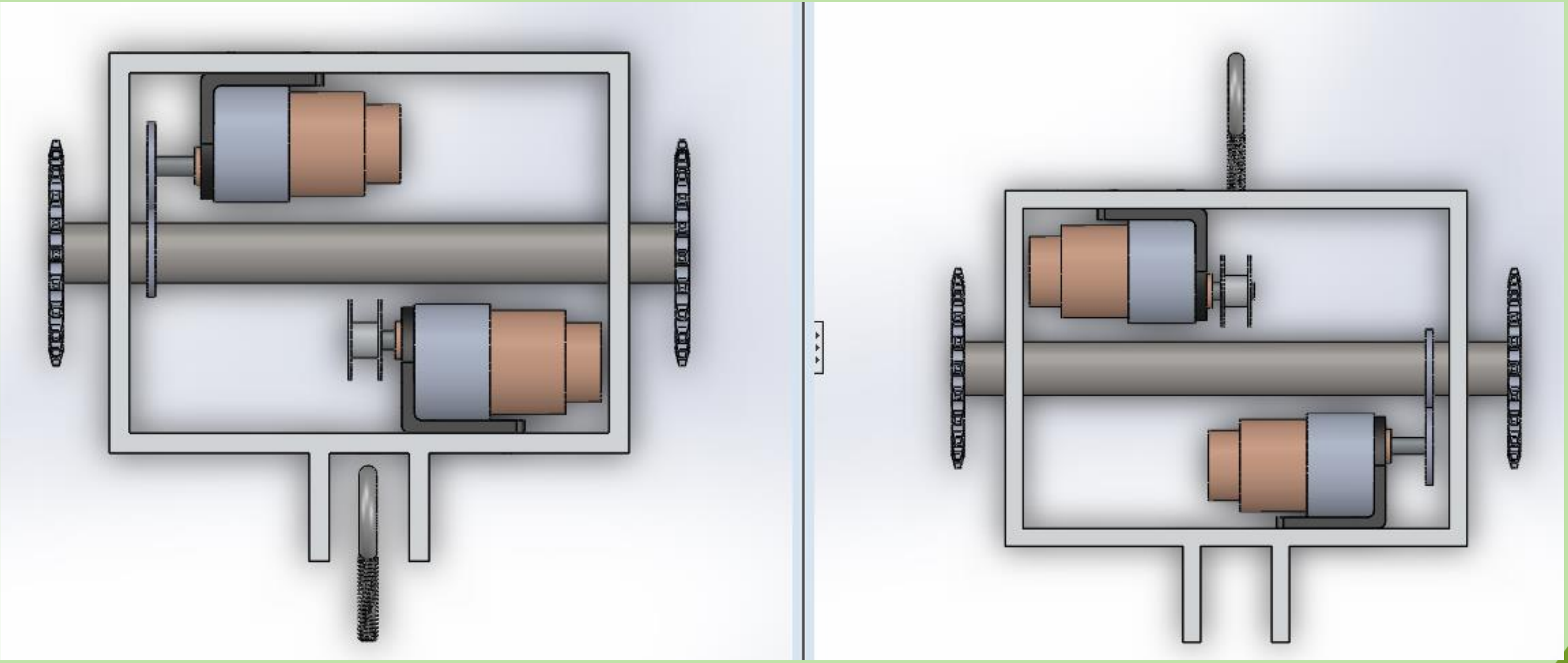
2nd Iteration – Motor Module <Head and Tail>



Head Module

Tail Module

Mechanical BOM

Mechanical BOM

#	Part Name	Part Number	Description
1	wheel shaft	8935k32	multipurpose 4140/4142 Alloy steel, Diameter 0.75
2	wheel bushing	6391k256	oil-embedded Sleeve Bearing, ID 0.75",OD 7/8",length 0.5"
3	washer	94589a470	Aluminum washer, ID 0.755", OD 0.995, max thickness 0.054"
4	Steel strip (wire)	9075K403	Blue-Finished and polished 1095 spring steel, thick 0.032",width 0.25", length 5'(ft)
5	Aluminum helix wire	8904K73	Aluminum round wire, 0.064"OD, .25 spool, 67ft long
6	dowel connector	97325a490	Low-strength Aluminum dowel pin, Diameter 0.25", length 1"
7	Shoulder screw	91259A157	Allow steel shoulder screw, 0.5" shoulder, 5/32" length thread, 4-40 thread size
8	eye bolt connector	3013t45	Steel eyebolt, no shoulder, for lifting, thread 1/4"-20, thread length 1"
9	eye bolt washer	90945a760	18-8 SS washer, ID 0.255", OD 0.468", max thickness 0.034"
10	eye bolt nut	90499a029	High-strength steel hex nut, thread 1/4"-20, grade 8
11	winch spool	1115 - 24T	Aluminum 6061 spools, 25.2mm OD, 11.25mm drum diameter, 10.5mm width
12	aluminum sheet for wheel	8975K87	Aluminum 6061, .25"thk, 3"width, 6"length

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Mechanical BOM

- Target Budget: $2000
- $500 for electronics

	Body	Motor	Total
Cost per module	126.96	203.62	330.58
Number of modules	7	3	10
Total	888.72	610.86	1500

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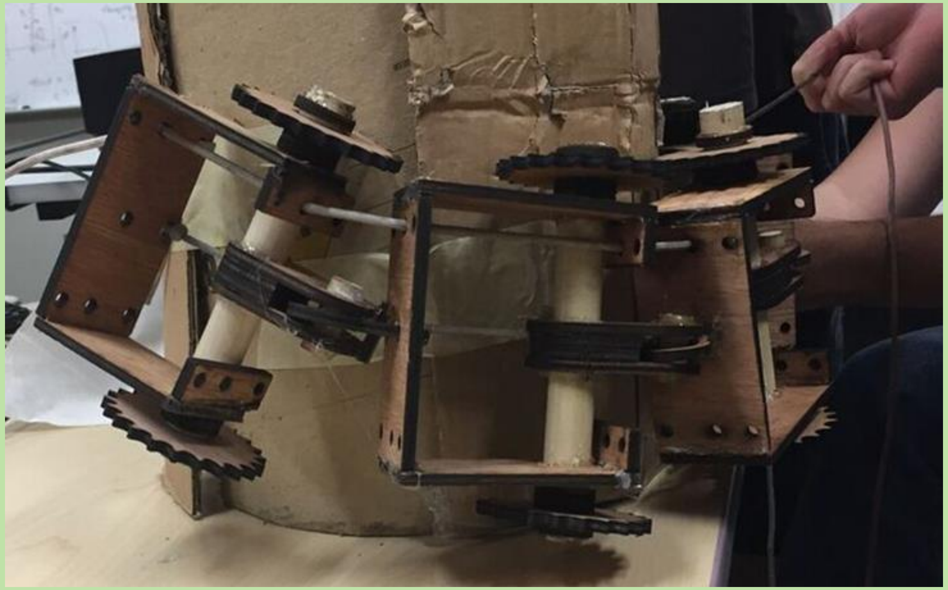
Preliminary Tests

Clamping Test

- 11 lb was maximum weight before slippage at a tension of 18 lb

Helix Test

- Proved successful, however pitch angle limited by car connector



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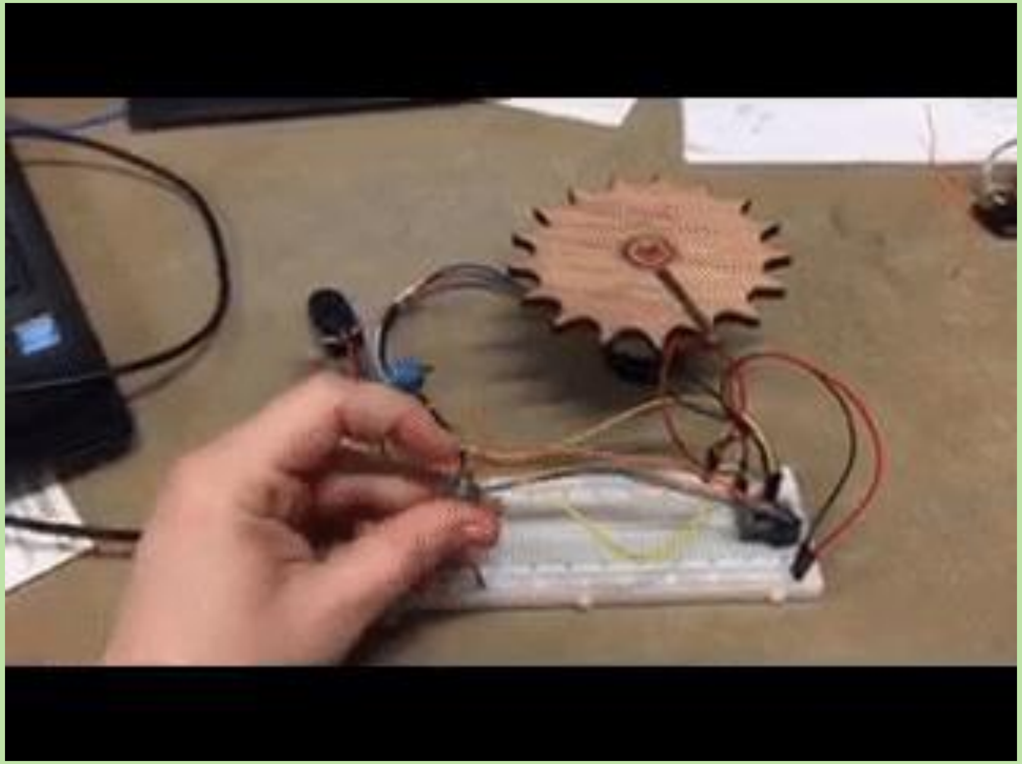
Electronics – What we have done



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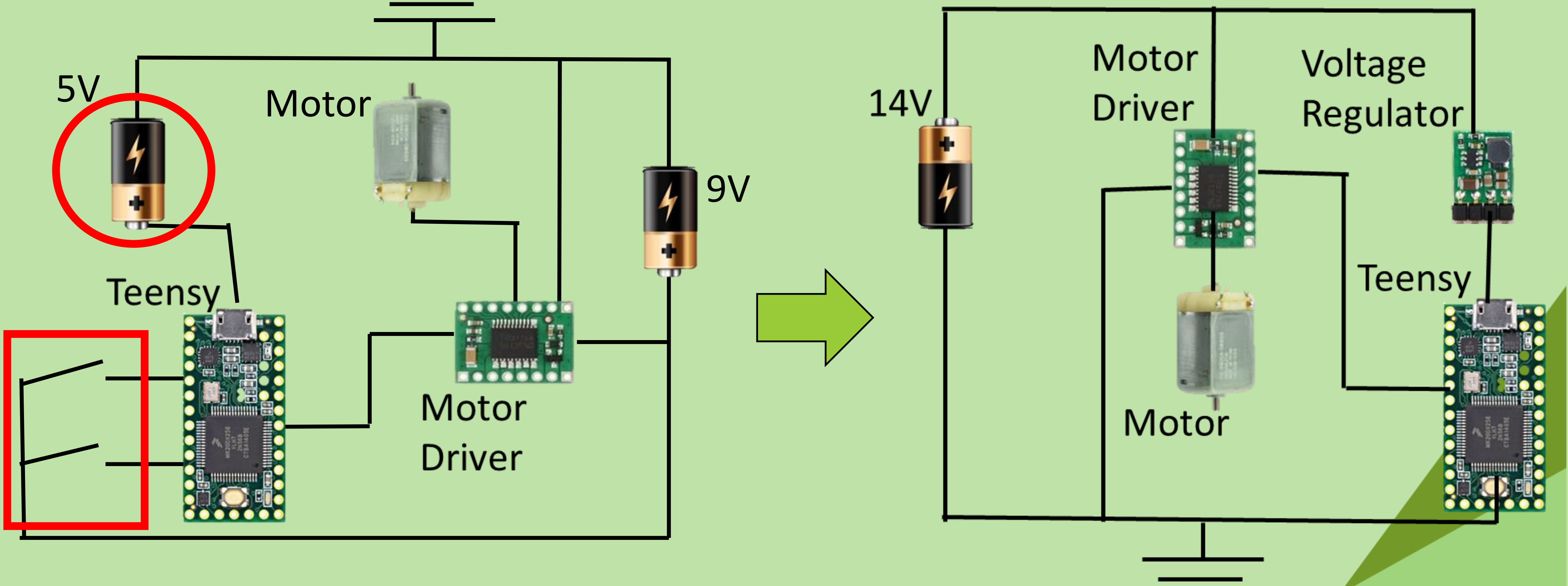
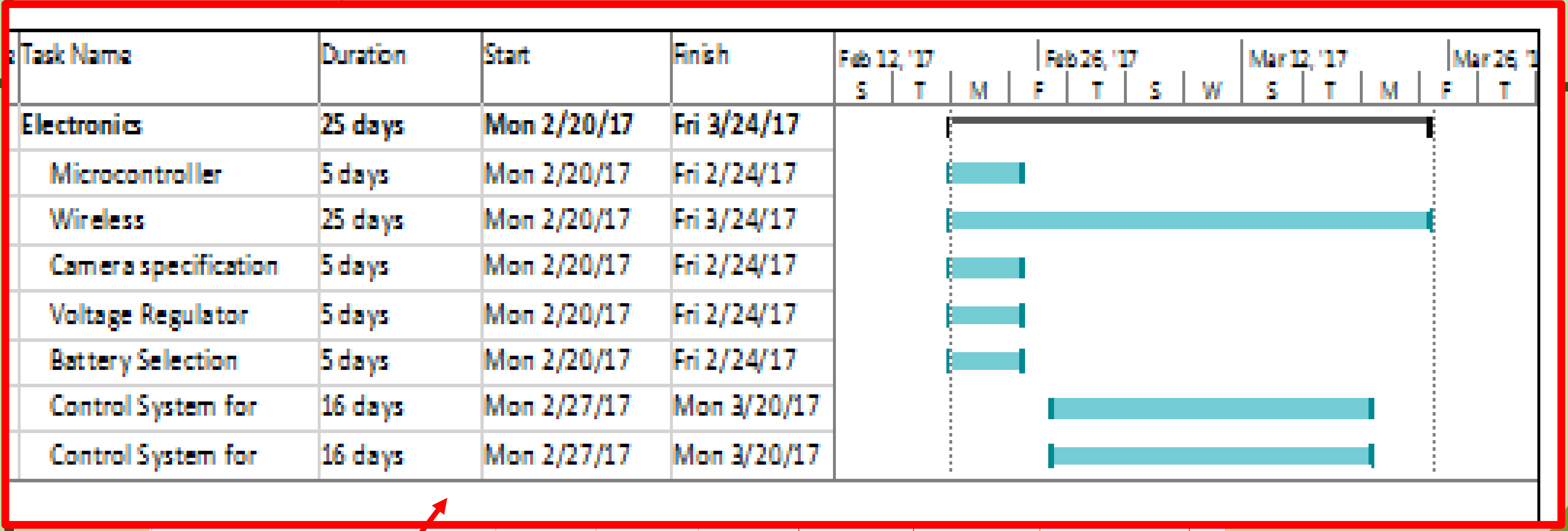
Electronics – What we need to do





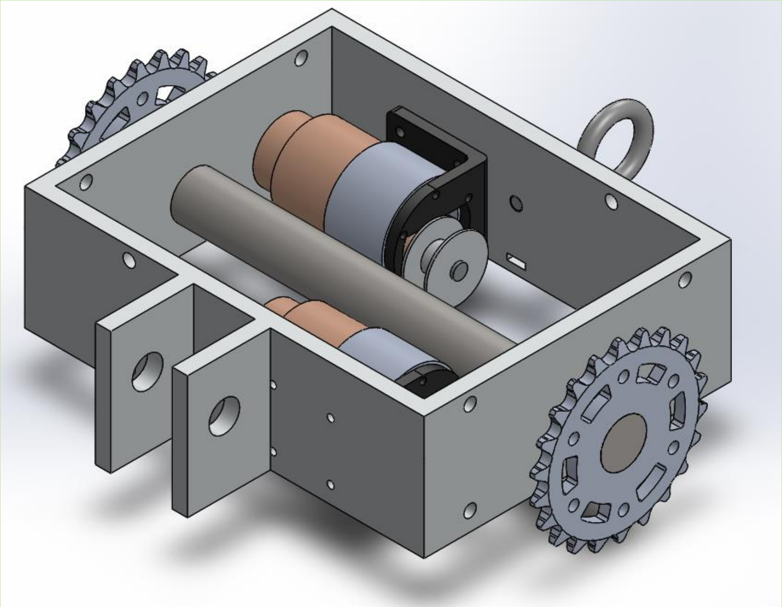
Task Name	Duration	Start	Finish
Electronics	25 days	Mon 2/20/17	Fri 3/24/17
Microcontroller	5 days	Mon 2/20/17	Fri 2/24/17
Wireless	25 days	Mon 2/20/17	Fri 3/24/17
Camera specification	5 days	Mon 2/20/17	Fri 2/24/17
Voltage Regulator	5 days	Mon 2/20/17	Fri 2/24/17
Battery Selection	5 days	Mon 2/20/17	Fri 2/24/17
Control System for	16 days	Mon 2/27/17	Mon 3/20/17
Control System for	16 days	Mon 2/27/17	Mon 3/20/17

Ordering of parts	16 days	Mon 2/27/17	Mon 3/20/17
Machining of custom parts	16 days	Mon 2/27/17	Mon 3/20/17
	4 days	Mon 2/27/17	Thu 3/2/17
Assembly of final design	6 days	Mon 3/20/17	Mon 3/27/17
Testing of final design	11 days	Mon 3/27/17	Mon 4/10/17

Electronics

Summary

- Iterated model was designed
  - Fixes helix generation
  - Allows for better clamping
  - More stability and inside space
- Head and tail modules designed
- Preliminary cost calculated
- Electronic components being tested
- Parts to be ordered by the end of the week



References

- P. Polchankajorn and T. Maneewarn, “Development of a helical climbing modular snake robot,” in 2011 IEEE International Conference on Robotics and Automation, May 2011, pp. 197–202.

- Snake Robot: http://farm4.staticflickr.com/3779/9313104039_867fafb326.jpg

- Pine tree: https://img1.cgtrader.com/items/152956/f9362d2d16/pine-tree-collection-3d-model-obj-3ds-fbx-3dm-dwg.jpg

- http://www.dot.state.mn.us/bridge/pdf/insp/USFS-TimberBridgeManual/em7700_8_chapter03.pdf

QUESTIONS?