Development of a Helical Path Tree Climbing Snake Robot

Final Design Presentation

Team 10

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Problem Definition

- The current process for removing large trees is expensive and dangerous
- There are 200 tree-related fatal injuries every year
- Fallen trees cause over $1 billion worth of damage annually

Tree Removal Services

- Removing Process:
  - De-limbing (‘pruning’) tree on the way up
  - Cutting small segments on way down (‘topping’)
  - Cut at base once at controllable height
- Price ranges from $150-$2,000
  - Complexity of job
  - Height of tree

Current Alternative Options

Chainsaw

- Requires specific set of skills
- Very dangerous

Tree Pruning Robot

- Only removes branches
- Still in development

Ponsse Scorpion

- Extremely expensive
- Mainly for deforesting

Project Goal Statement

Original Scope:

- To climb a tree in a helical manner and cut it down via the method of 'topping'.

Revised 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.

Project Goal Statement

Objectives:

- Our robot must be able to:
  - Climb a tree diameter between 10-30 inches
  - Ascend at a minimum speed of 1 ft/min
  - Carry a payload of at least 10 lbs
  - Provide video feedback via a camera

Customer Requirements:

- User-friendly
- Affordable
- Effective
- Reliable

Focus on pine trees

- Straight and round

Justin Morales

Design Considerations - Overview

How do we keep the snake robot on the tree?

How can we ensure the snake is properly placed on the tree?

How can we generate a helical path?

How does the snake move once in a helical configuration?

Design Considerations - Clamping

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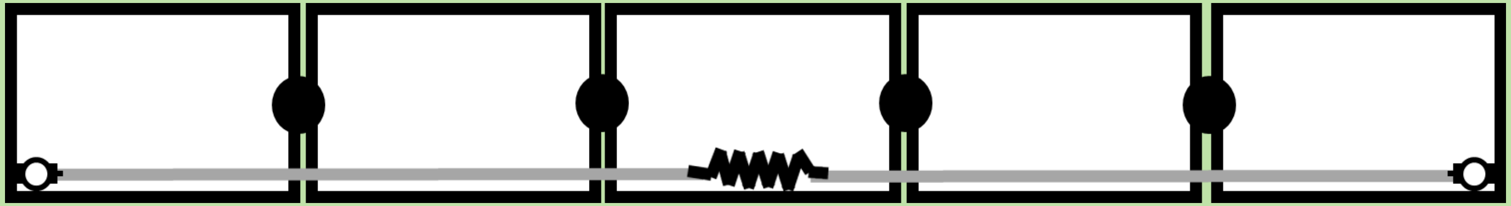
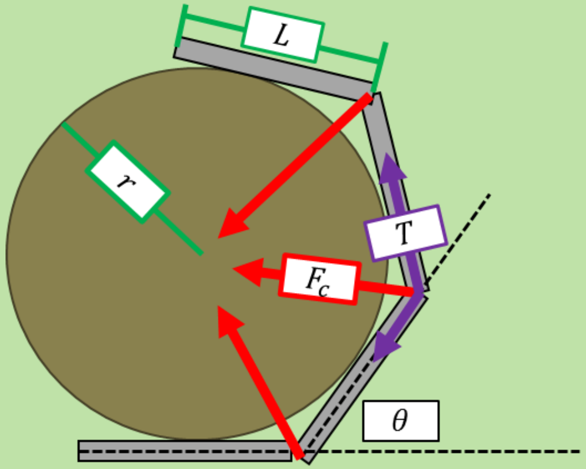




$$\theta = 2\tan^{-1}\left(\frac{L}{2r}\right)$$

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

Final torque needed for clamping ≈ $16\ lbf \cdot ft$

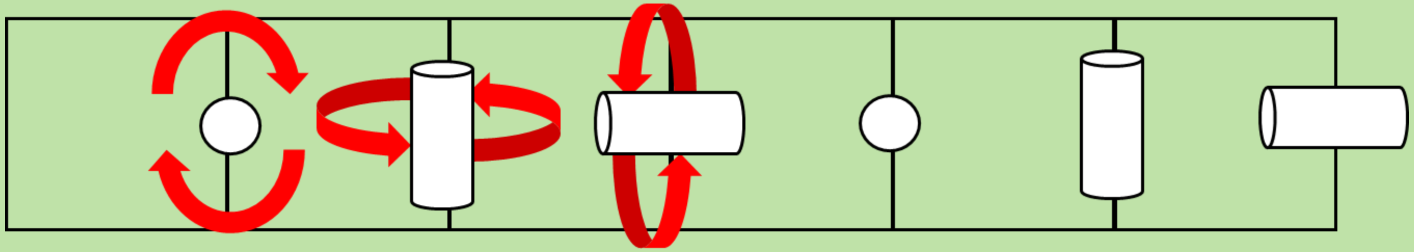
Design Considerations – Wheel Orientation

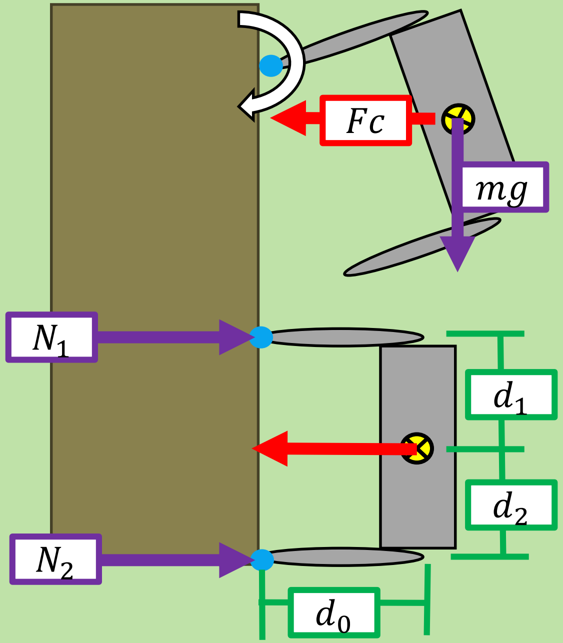
How do we keep the snake robot on the tree?

How can we ensure the snake is properly placed on the tree?

How can we generate a helical path?

How does the snake move once in a helical configuration?





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

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

Final force needed for orientation ≈ $20\ lbf$

Esteban Szalay

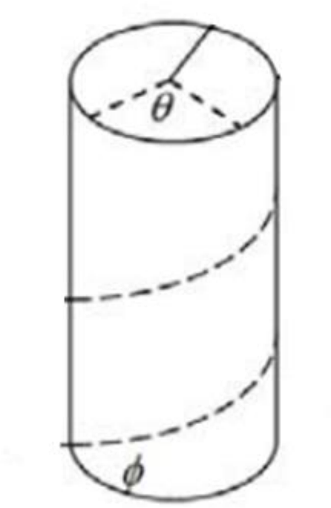
Design Considerations – Helix Generation

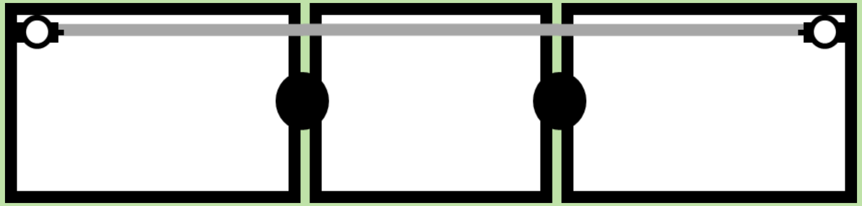
How do we keep the snake robot on the tree?

How can we ensure the snake is properly placed on the tree?

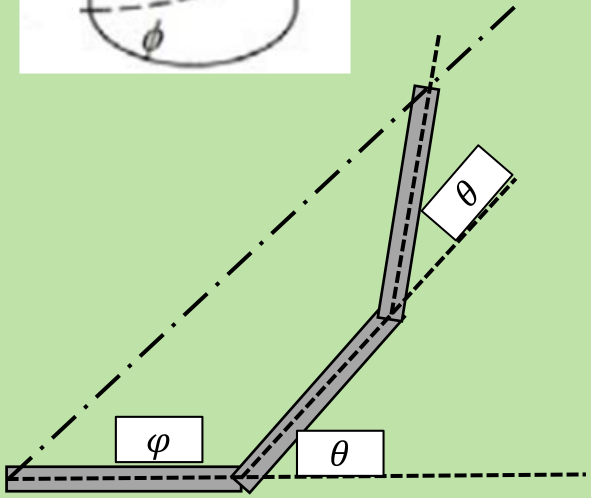
How can we generate a helical path?

How does the snake move once in a helical configuration?





Helix Wire



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

φ is the total pitch angle
α is the module-to-module angle
n is the number of modules

Design Considerations - Motion

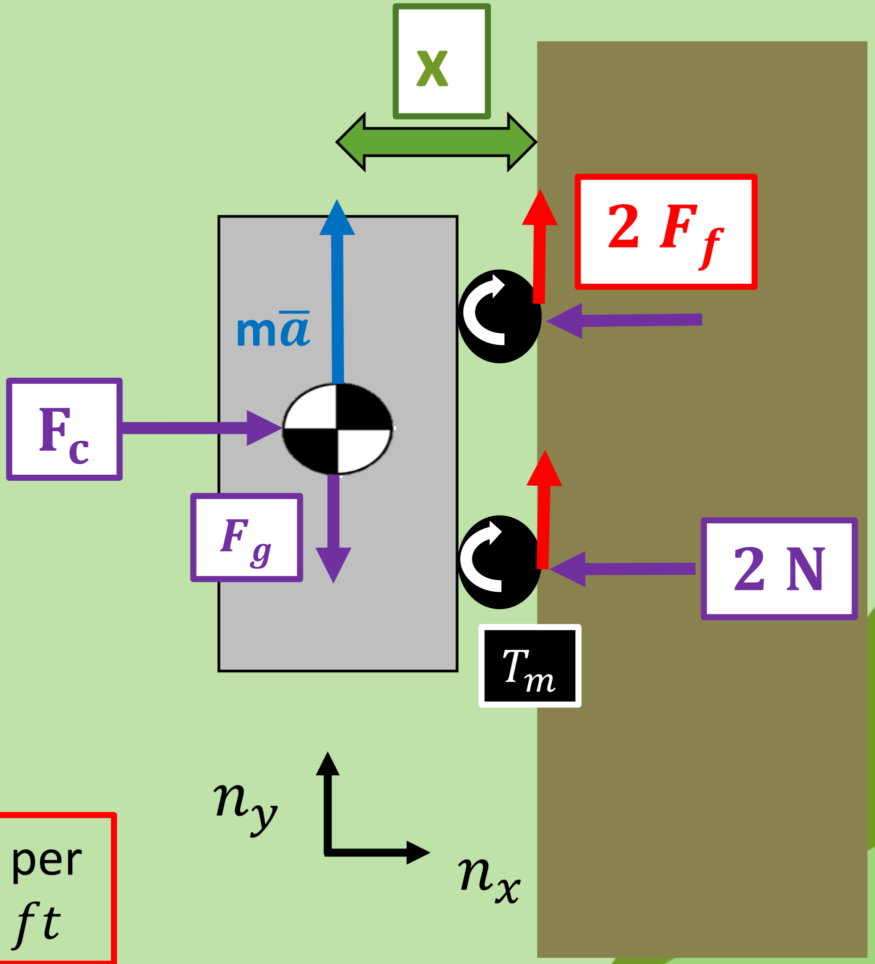
How do we keep the snake robot on the tree?

How can we ensure the snake is properly placed on the tree?

How can we generate a helical path?

How does the snake move once in a helical configuration?

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



Torque requirement per wheel: $T_m = 8\ lbf \cdot ft$

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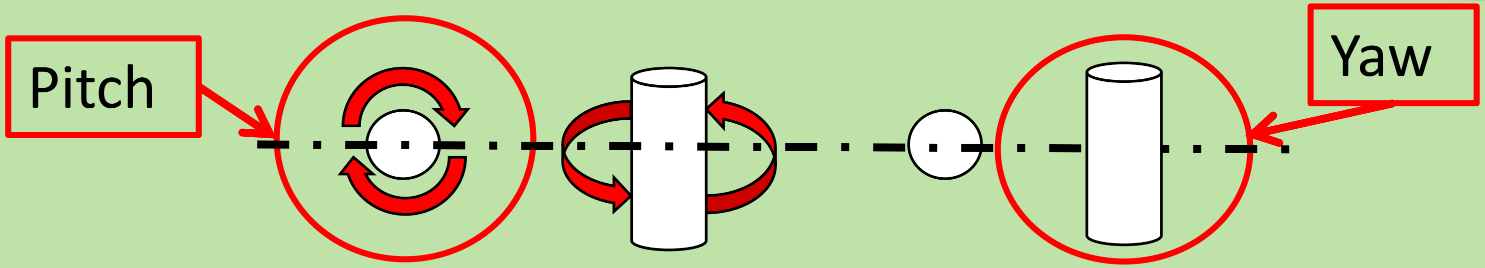
Previous Iterations

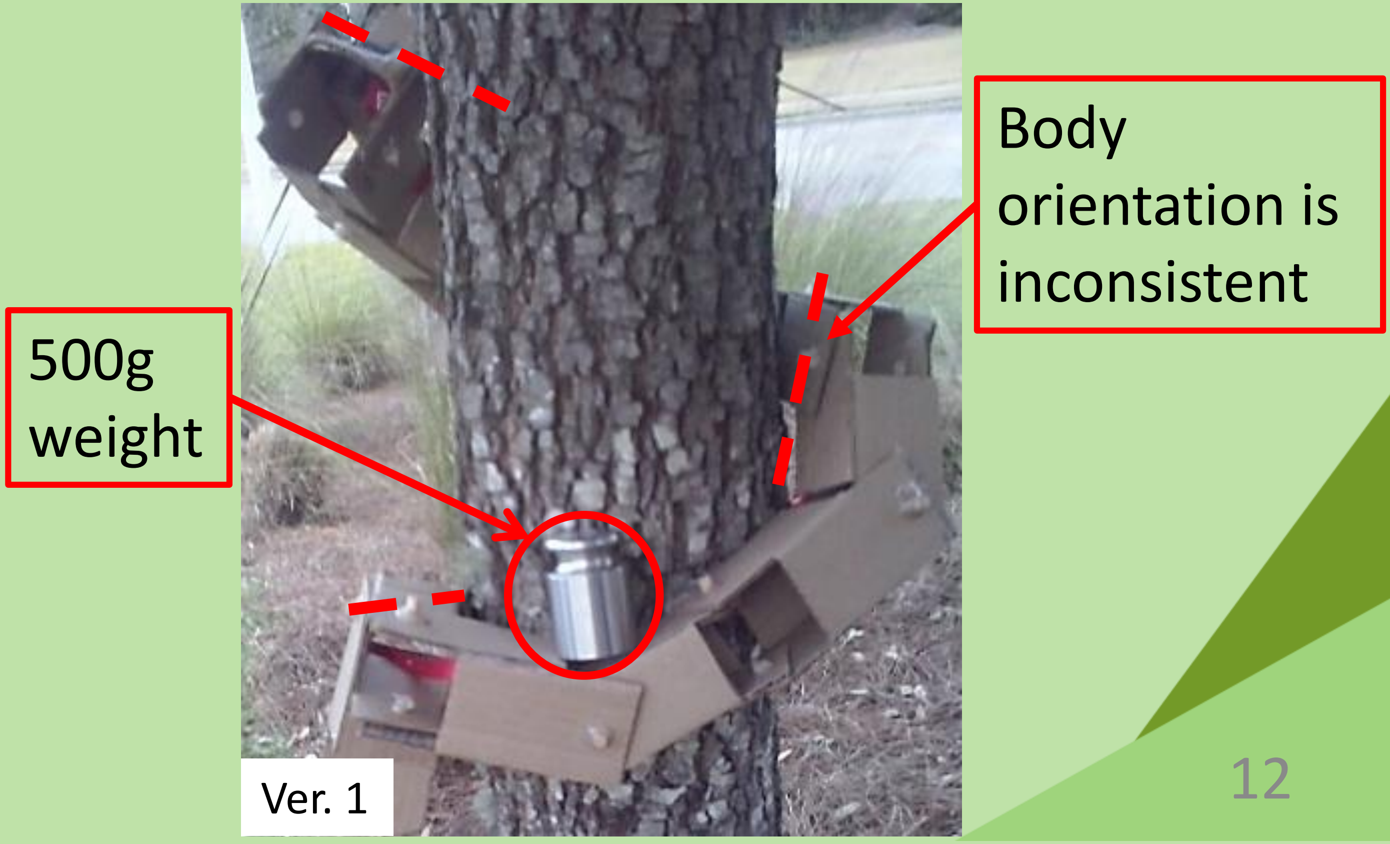
Prototype version 1

- 2 degrees of freedom (DOF)
- Alternating joint motions
- Effective link length is 1 module



Test

- Clamping – success
- Helix generation – success
- Body orientation – failed



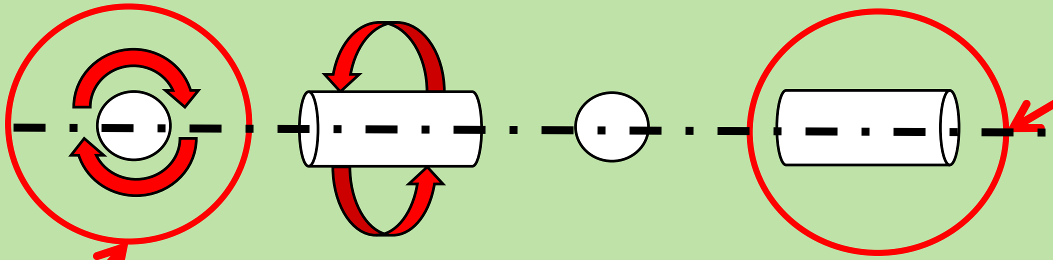
Previous Iterations

Prototype version 2

- Alternating joint motions
- Effective link length is 2 modules

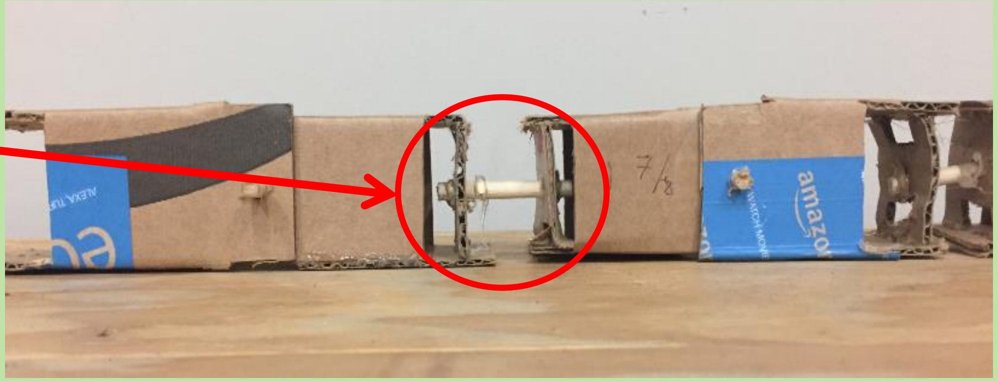
Test

- Clamping – success
- Helix generation – Failed
- Body orientation – success

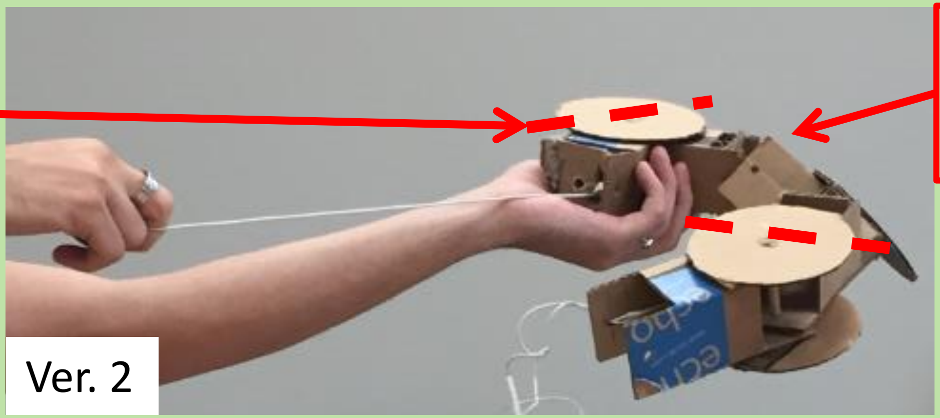


Pitch

Roll Joint

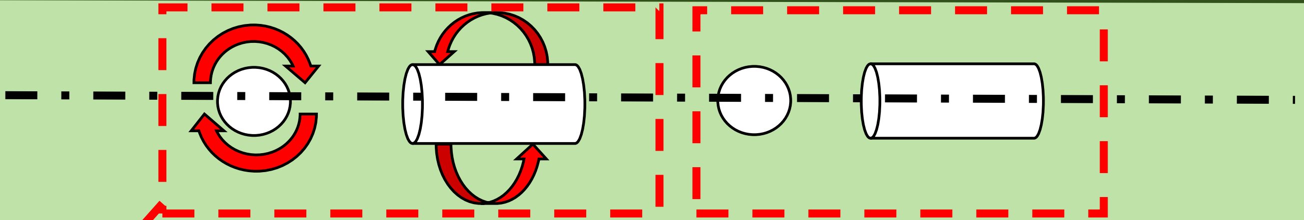


Wheel orientation is consistent



Clamping motion due to tension

Previous Iterations



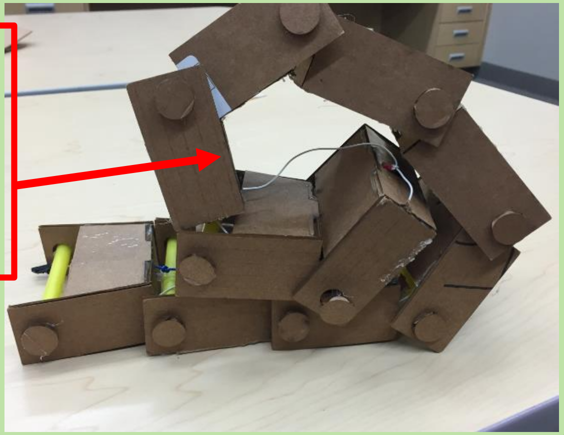
Prototype version 6

- Joint motions unified to one location
- Effective link length 1 module

Test

- Clamping – success
- Helix generation – unreliable
- Body orientation – success

Smaller clamping diameter



Clamping to smooth surface

Wheel location has consistent orientation

Previous Iterations

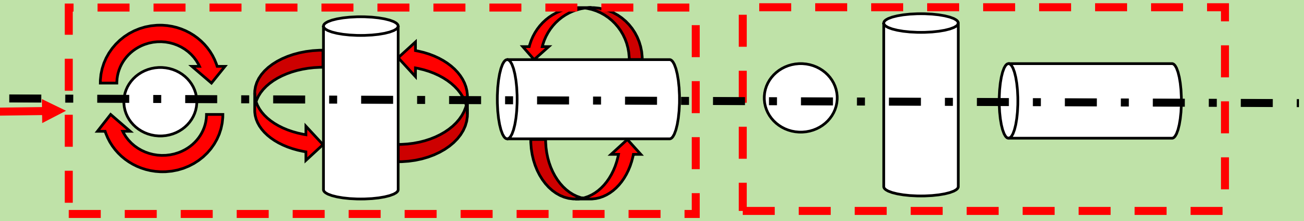
Prototype version 8

- 3 DOF

Test

- Clamping – Success
- Helix generation – Failed
- Body orientation – Success
- Locomotion – Fail

3 DOF at one joint



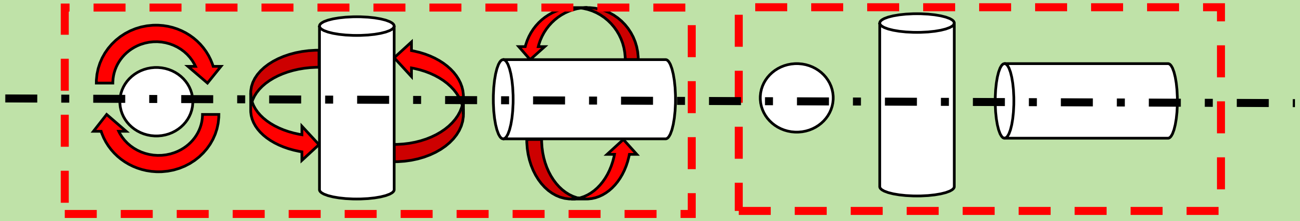
Clamped to tree with a 10lb distributed weight with 18lbf of tension

Clamping works for many diameter trees

Previous Iterations

Prototype version 9 - 10
- Differential steers robot to make helix
- Wheels moved to outside of module

Test
- Clamping – Partial success
- Helix generation – Success (v10)
- Body orientation – Success
- Locomotion – Shows promise

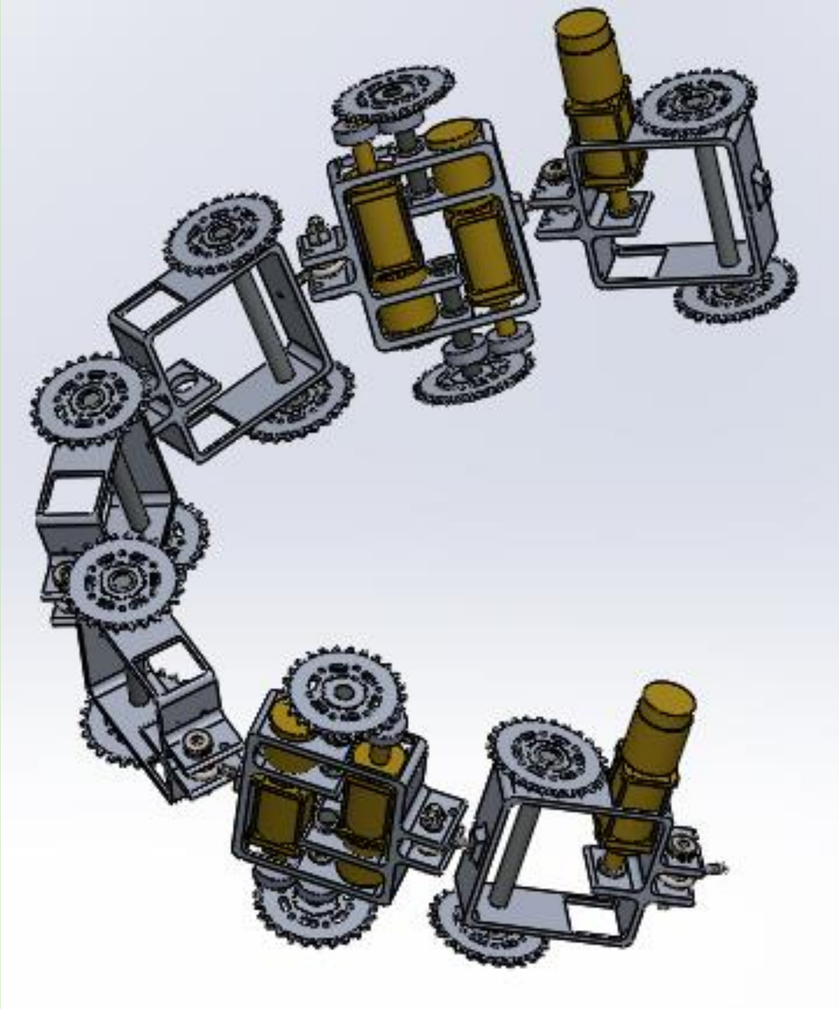



Ver. 9

Clamping requires a controlled pivot point


Ver. 10

Key Results



Clamping

- Clamping was consistently proven to work
- Can hold added weight for cardboard (1.1lbs) and wooden prototype (10lbs)

Helix

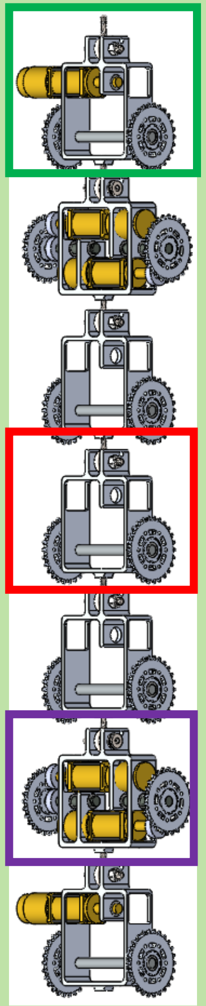
- Cable for helix generation failed
- Differential used to steer and drive robot successfully

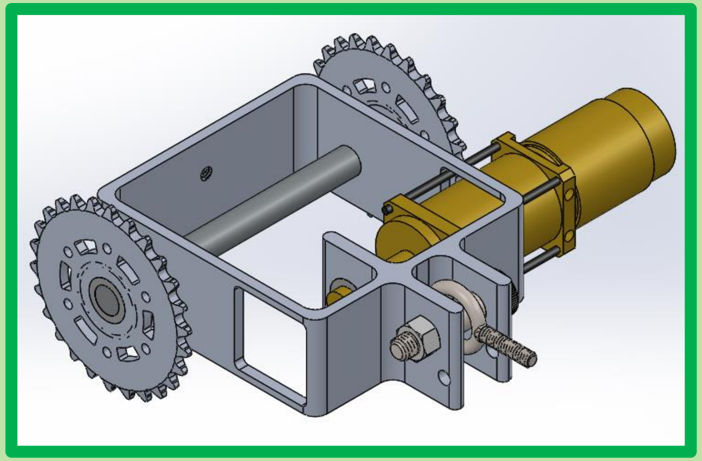
Wheel Orientation

- Needs 3 DOF for stable wheel orientation

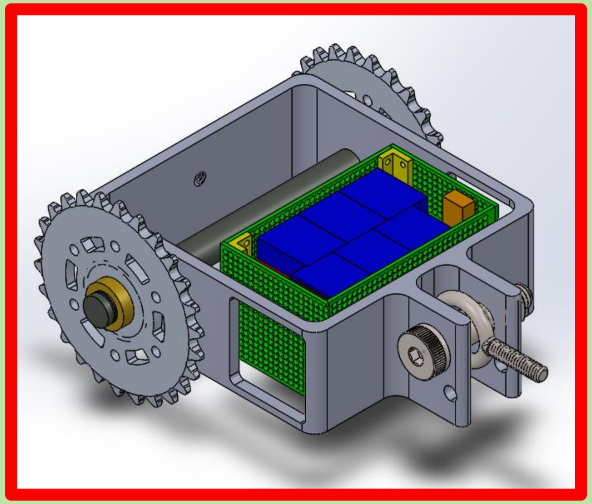
Elements work when decoupled

Final Design - Modules

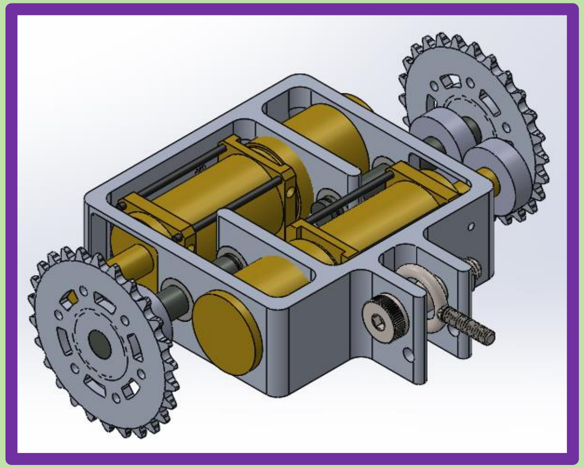




Clamping Module



Body Module



Motor Module

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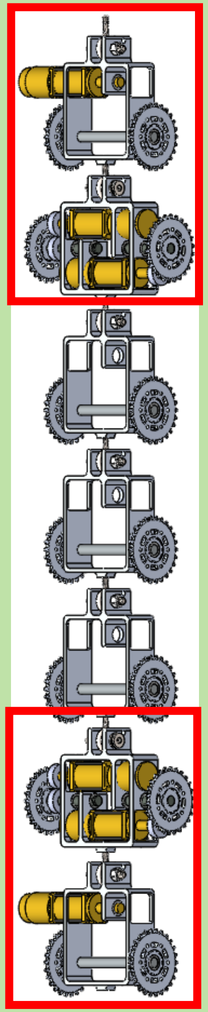
Final Design - Motors



Element	Motor (driving)	Gearbox (driving)	Total
Speed	19,300rpm	326:1	59.2 rpm
Torque (stall)	0.3602 lb-ft	326:1	117.4 lb-ft
Weight	7.7oz	11.4oz	1.194 lbs

Element	Motor (clamping)	Gearbox (clamping)	Total
Speed	19,300rpm	672:1	28.7 rpm
Torque (stall)	0.3602 lb-ft	672:1	242.1 lb-ft
Weight	7.7oz	11.4oz	1.194 lbs

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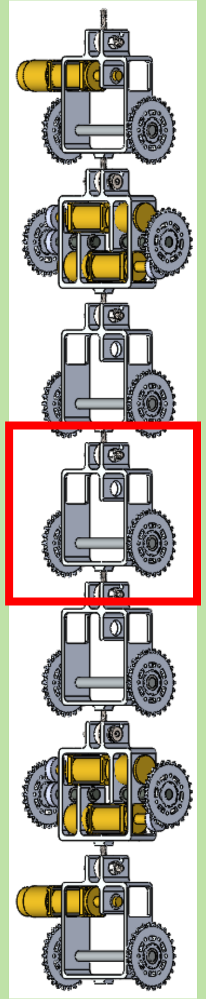
Final Design – Electronic Components



Component	Teensy	Wixel	Motor Driver	5V step-down voltage regulator	12V step-down voltage regulator	Camera	Monitor	Transmitter
Current draw (mA)	60.2	30	17A continuous	600	2,200	150	250	200
V in (V)	3.6-6.0	2.7-6.5	6.5-30	7-42	13.5-36	12	12	12
Voltage signal (V)	0-3.3, 5v tolerant	0-3.3	1.8,3.3,5v compatible	N/A	N/A	N/A	N/A	N/A
Max output current pin (mA)	10	4	N/A	600	2.2A	N/A	N/A	N/A

Teensy Microcontroller

Voltage Regulator

Motor Controller

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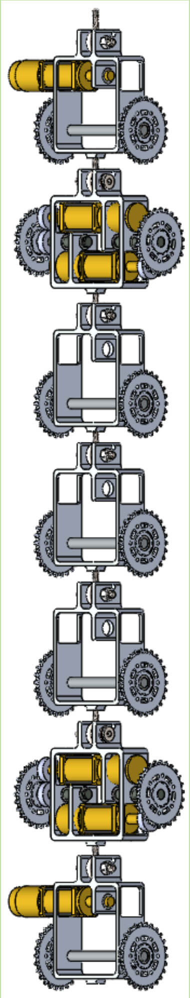
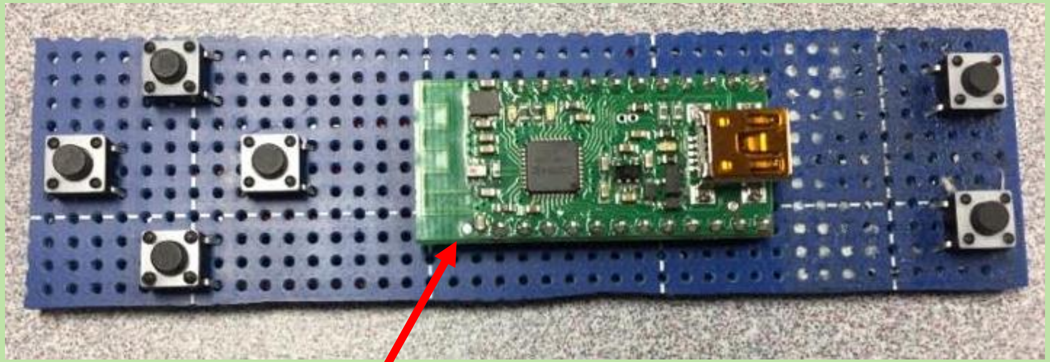
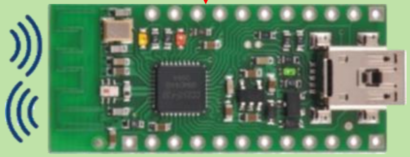
Final Design – Wireless and Camera





Wixel:
Wireless Communication



Camera:
Transmitter and
Receiver

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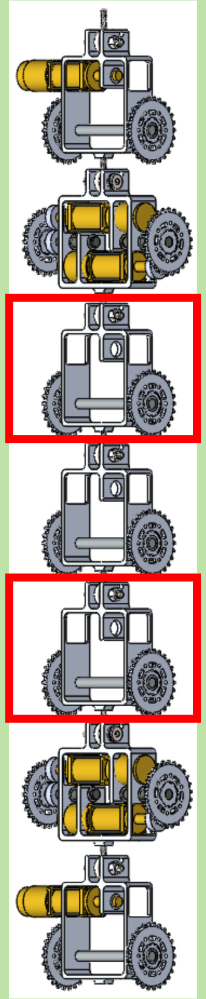
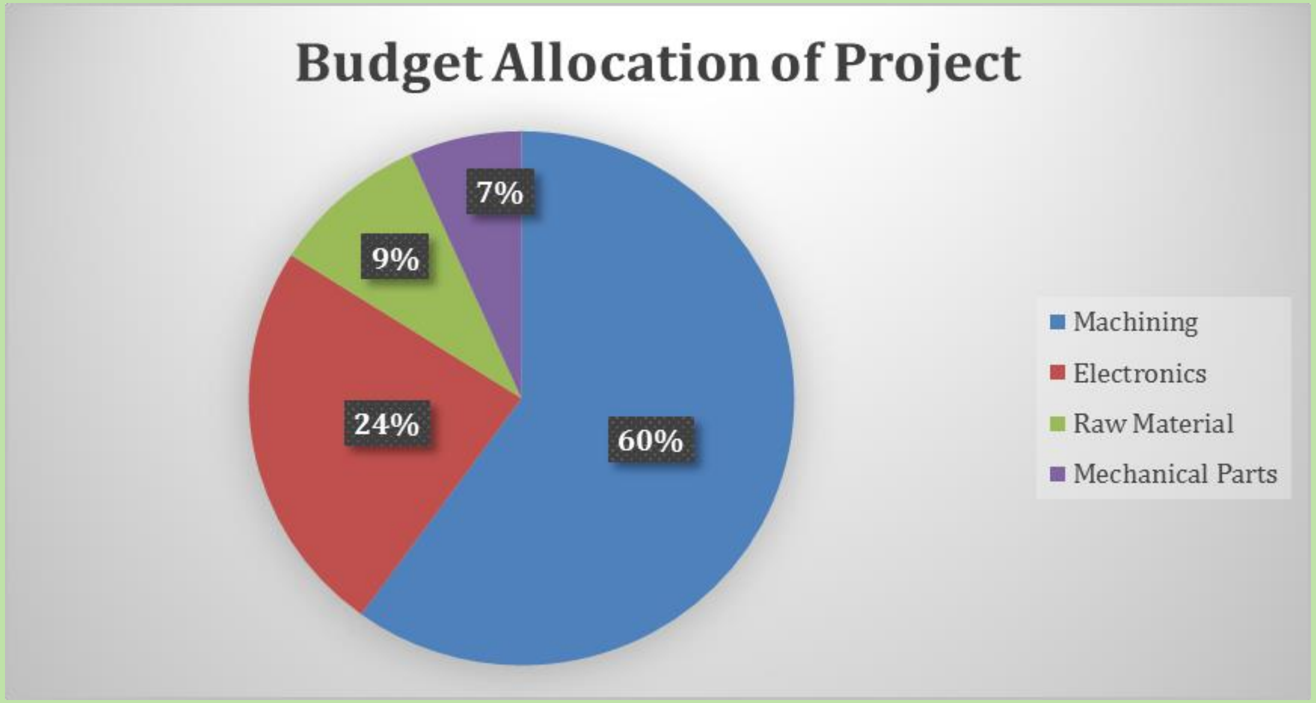
Final Design - Batteries



Component	Max Current Draw (A)	Battery Capacity (mAh)	Runtime (Capacity/Current)
Motor	12.0	2250	11min
Voltage Regulator	0.600	1000	1.6hr
Wixel	0.060	260	4.3hr
Camera	0.350	1100	3.1hr
Monitor	0.900	1100	1.2hr

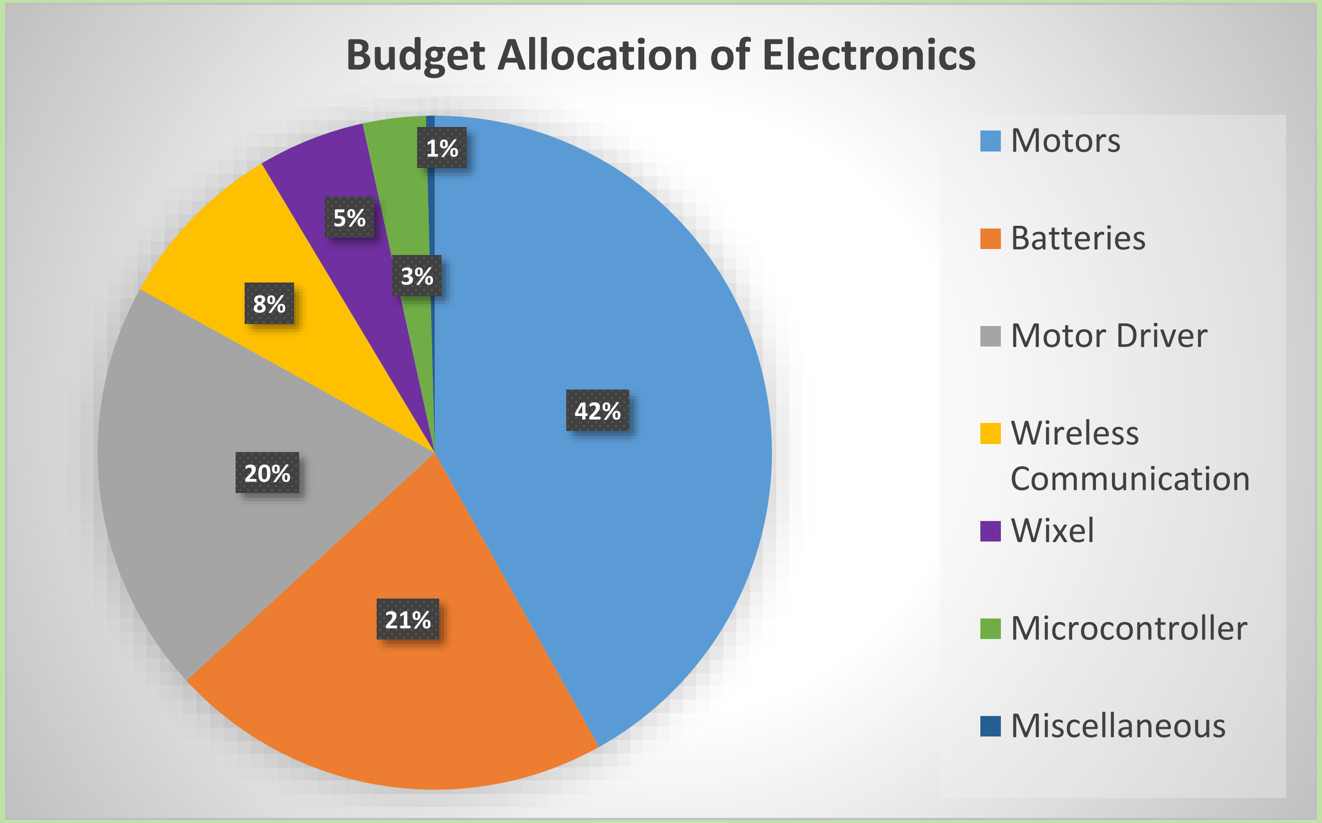
Batteries for Motor Operation

Cost of Design



Component	Cost (dollars)
Machining	2250
Electronics	900
Mechanical Parts	250
Total	3400

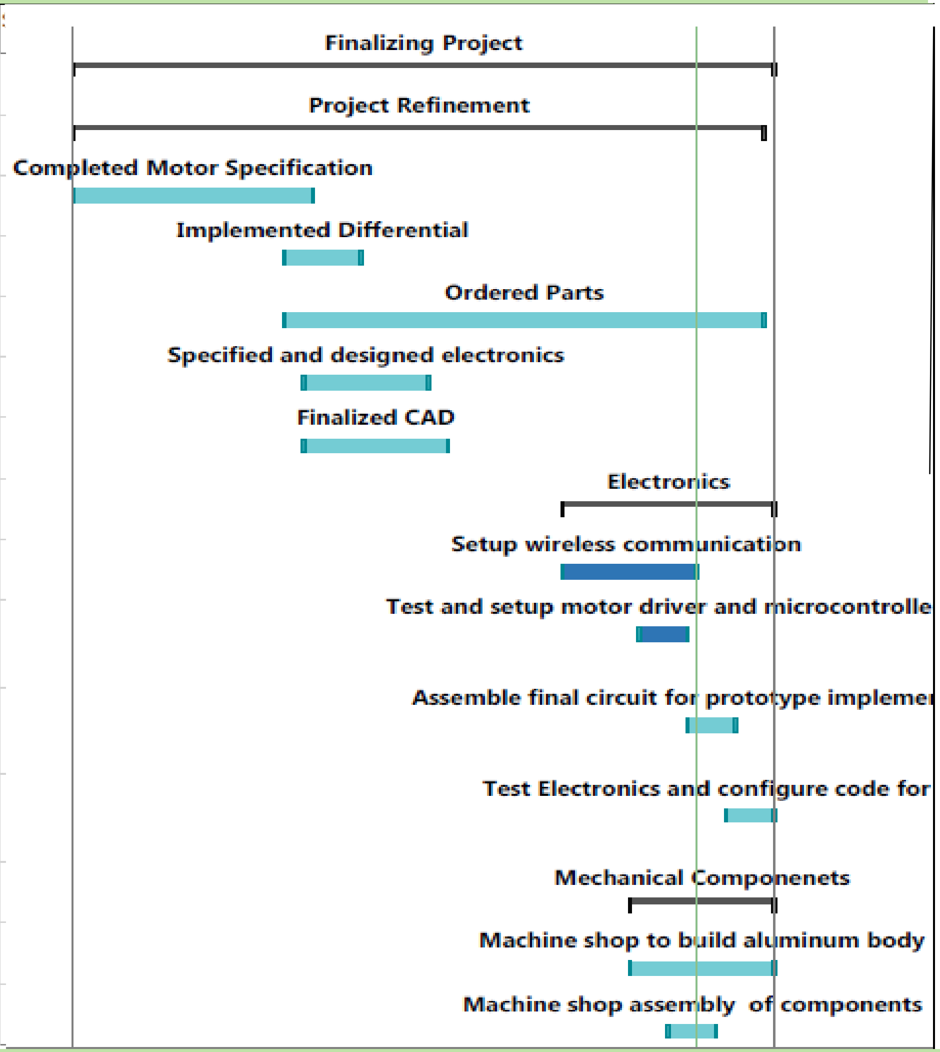
Cost of Design



Name	Cost (Dollars)
Motors	340.8
Batteries	173.1
Motor Driver	161.76
Wireless Communication	67.92
Wixel	41.9
Microcontroller	24.53
Miscellaneous	3.39

Closing Statements - Scheduling

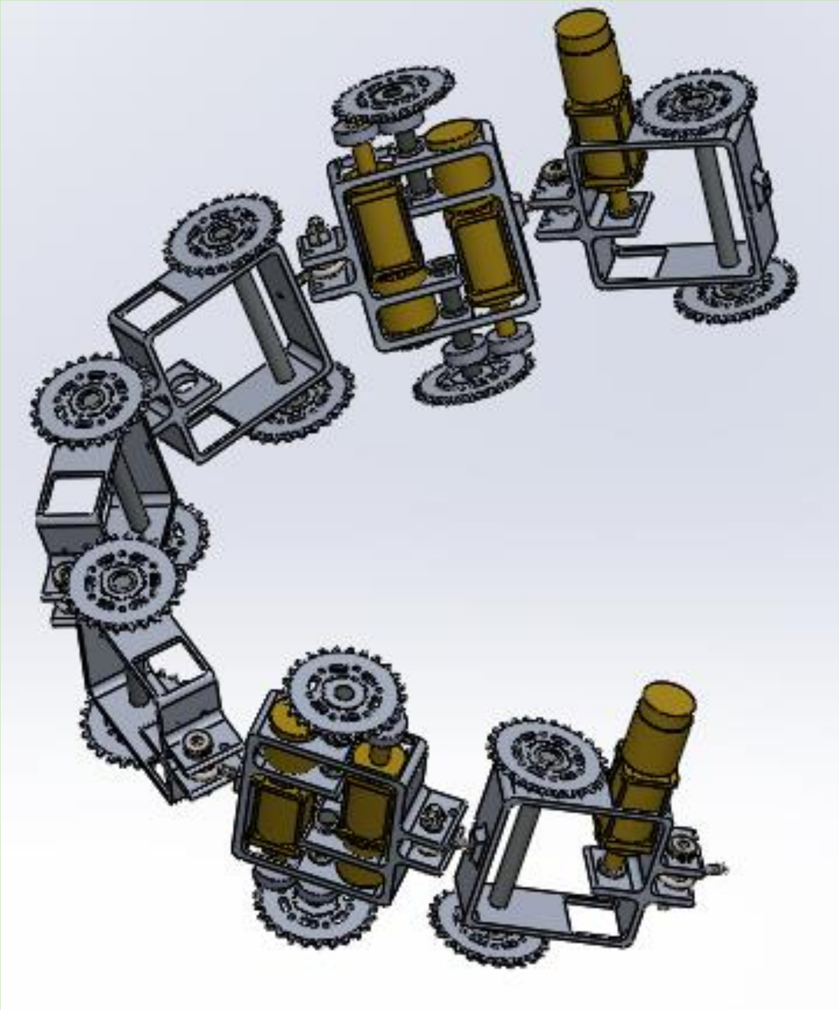
Task Name	Duration
Finalizing Project	**53 days**
Project Refinement	**52 days**
Completed Motor Specification	19 days
Implemented Differential	6 days
Ordered Parts	36 days
Specified and designed electronics	9 days
Finalized CAD	11 days
Electronics	**16 days**
Setup wireless communication	10 days
Test and setup motor driver and microcontroller	3 days
Assemble final circuit for prototype implementation	4 days
Test Electronics and configure code for testing	5 days
Mechanical Componenets	**11 days**
Machine shop to build aluminum body	11 days
Machine shop assembly of components	5 days



Closing Statements – Future Work

1. Test motion and develop experimental model of torque requirements for motion along tree
2. Develop control systems to maintain pitch angle and climbing speed
3. Find analytical model verified by further experimentation relating tension and clamping force
4. Test with concentrated payload to replicate cutting arm
5. Implement cutting arm

Summary



Tree removal is a complex and dangerous task

- The project's aim is to increase safety by reducing direct involvement

Iterative design aided in the generation of successful solutions for individual components (clamping, helix, driving)

- Climbing aspect resolved
- Consolidated test pending

Motor selection was key

- Final design revolved around motor dimensions
- Motor selection influences a majority of the budget

Questions?