Product Design Lab 2: 2016

Unmanned Tree Climber

For Coconut and Arecanut Trees

Team J

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Problem Statement:

To develop an inexpensive and robust mechanism capable of climbing slender trees such as arecanut and coconut, while being operated from ground level by a user.

Motivation:

Trees such as arecanut and coconut form a sizeable portion of the commercial agricultural sector in southern India. Presently, harvesting crops from these trees requires the use of skilled labour, as climbing their smooth, slender trunks to pluck the fruits is not only difficult, but also quite dangerous.

By building a mechanism that is capable of climbing a tree and harvest the fruits without the need for a person to climb, the harvesting process can be made much cheaper and safer.

Design Parameters:

- Compactness and Portability of the mechanism.
- Ease of Deployment, i.e. how easily can the mechanism be attached and detached from a tree.
- Mass of the Mechanism
- Total Energy expended in climbing a tree
- Adaptability, i.e. the range of tree diameters and surfaces the mechanism can work on.

Target Customers

- Small scale farmers
- Urban residents with a small number of coconut/arecanut trees in their residence

Market Requirements/Challenges

- Due to the target market of the product, ensuring low purchase as well as maintenance cost is of paramount importance. However, reduction in cost generally comes at a trade-off with decrease in robustness and reliability
- Ease of operation, as well as low operation cost are critical to the success of the prototype.
- On the other hand, the prototype must be capable of adapting to a large number of trees. This inevitably bring complexity to the design, decreasing the user friendliness.

Analysis of Existing Product(s):

A similar product, named 'Wonder Climber' was found to have been developed in Kerala, India. While this product meets the basic functional requirements, i.e. it is capable of climbing coconut trees, it is not commercially successful.

The product has the following advantages:

- It is purely mechanical and does not require any electrical input or any form of energy other than human force to function.
- It has an integrated cutting tool and collector mechanism to harvest the coconuts.
- To bring the product back down, the user must only pull a string. The descent of the product is gradual and controlled rather than a free fall.

Though exact specifications could not be obtained, we perceived the product to have to following shortcomings.

- The entire mechanism is quite bulky and heavy
- Deploying the mechanism is a complex and time consuming process
- The mechanism appears to be quite complicated to manufacture, hence it may be quite expensive.

Concepts and Comparison

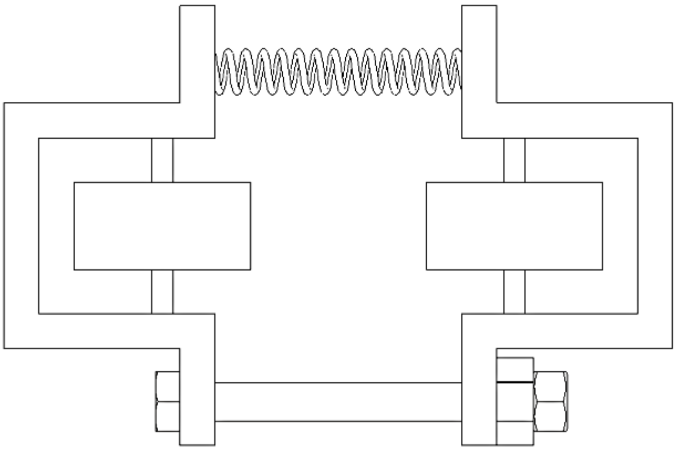
The components of the product were largely divided on basis of function into three categories

- Gripping: These are the components required to ensure that the mechanism is capable of stably remaining at rest under the action of its own weight and an external input force, if any. Also, the gripping components must perform this function on not just one tree, but a range of tree diameters and surfaces.
- Actuation/Motion: These are the components required to move the mechanism vertically on a tree trunk.
- Retrieval: Components required to bring the mechanism back down once it has completed its purpose.

Analysis of Gripping Concepts

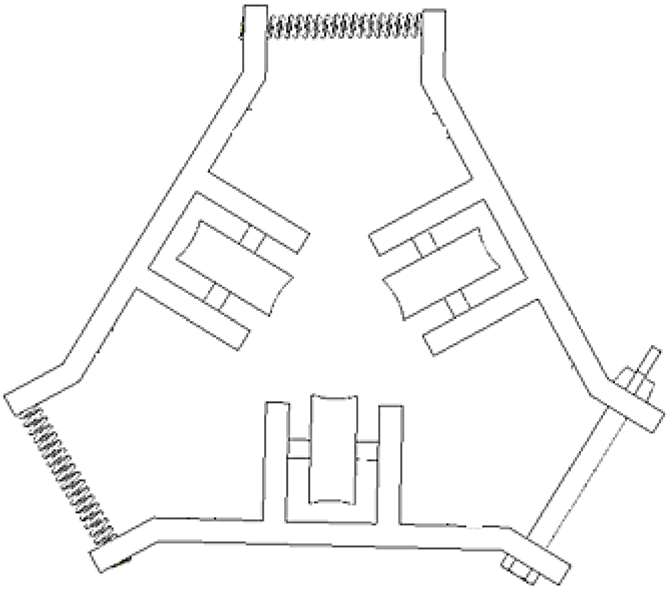
For gripping, two similar design were proposed. Both designs consisted of a small number of rigid members connected together by springs. While wrapped along a tree, the tension in the springs would generate normal force between the tree and the rigid components, enabling the frame to support itself using friction.

- **Frame Design 1: Two sided frame**



This frame uses two rigid members on either side of the tree trunk, connected together on one side by a spring. On the other side, it is connected by a long bolt and nut, which can be used to attach/detach the frame around a tree and also to adjust the initial extension in the spring, in order to allow better performance over different kinds of trees.

- **Frame Design 2: Three sided frame**



This frame is similar in function to the first design, however it uses three frame members rather than three to provide greater stability and adaptability

- **Comparison**

	Mass	Stability	Adaptability	Ease of Deployment
Two Sided	+	-	-	-
Three Sided	-	+	+	+

The two sided frame is lighter as well as easier for a user to mount around a tree. However, the three sided frame is more stable due to the larger area od contact with the tree. Due to its geometry, it also provides better contact over a range of diameters.

Therefore, the three sided frame was selected.

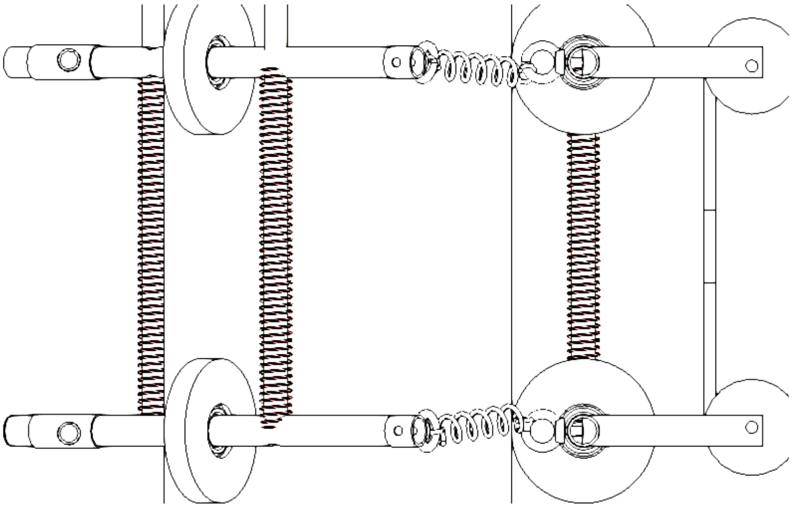
Analysis of Actuation Components

Three methods of actuation were proposed and compared

- **Actuation Scheme 1: Using Motors**
  This design would utilize of the frames discussed above, with a motor being connected to each of the rollers as shown. In order to save weight, the motors would be powered by cables from the ground rather than an on-board battery. The primary benefit of this scheme is the simplicity of its implementation and a low number of moving components.

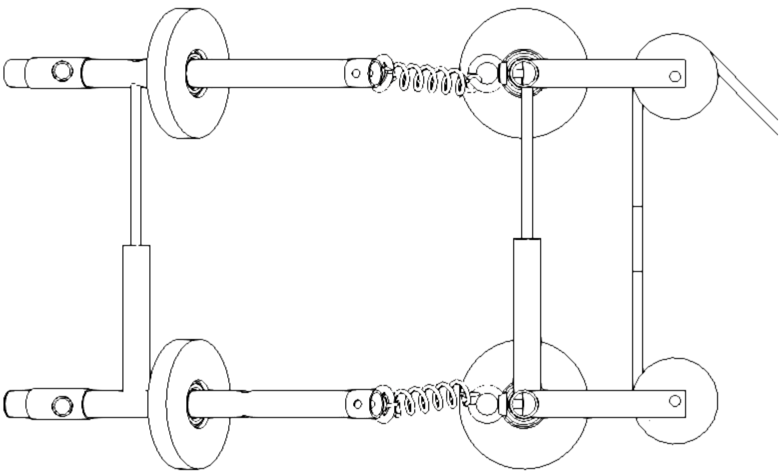
The next two actuation schemes discussed both use a caterpillar like motion to climb up a tree. This system uses two the frames discussed above placed one above the other and connected together by a deformable element. Both these frames would be constricted to move only in the upward direction by mounting their rollers on ratchets. Thereon, an input from the user would first cause one of the two frames to move upwards while the other remains fixed. In the next part of the cycle, the first frame will be at rest while the other moves relative to it. In this way, a caterpillar like periodic motion would cause the mechanism to move upwards.

- **Actuation Scheme 2: Spring Based Actuation**



In this scheme, vertical springs would be used to connect the upper and lower frames. A rope would be fixed at the lower frame, passed through a pulley on the upper frame and the free end will be available for the user. When the user pulls at the rope, the upper frame remains fixed due to its ratchets, while the lower frame moves upwards, compressing the vertical springs. When the user releases the rope, the springs would return to their natural length by pushing the upper frame in the upward direction. Thus, the entire mechanism would move upwards by a distance equal to the net length of rope that the user pulls. The benefit of this scheme is the fact that does not require an external source of energy to operate.

- **Actuation Scheme 3: Hydraulic Actuation**



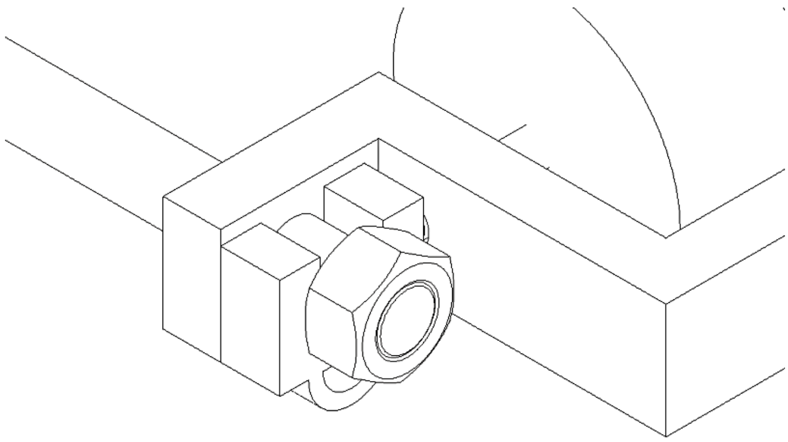
This scheme uses a similar kinematic cycle as the previous scheme. However, rather than using a spring to provide the actuating forces, a hydraulic piston may be used to move the two frames relative to each other. While this system is quite complex, it was proposed due to the availability of water pumps at most agricultural sites, allowing a system that could work with minimal permanent investment at the user's part.

- **Comparison of Actuation Schemes**

	Mass per Frame	Human Effort	Other external Energy Input	Cost	Complexity
Motor	-	+	-	-	+
Spring	+	-	+	+	0
Hydraulic	0	+	-	-	-

The motor actuation provides the simplest implementation of all proposed designs, however its high cost, high weight and requirement of electricity prevent it from being the most optimal solution.
The hydraulic actuation provides no real benefit other than reduced human effort, and thus is not the optimal solution either.
The spring actual scheme is lightweight, inexpensive and reasonably simple to implement. Thus, this scheme is selected.

Concept for Retrieval



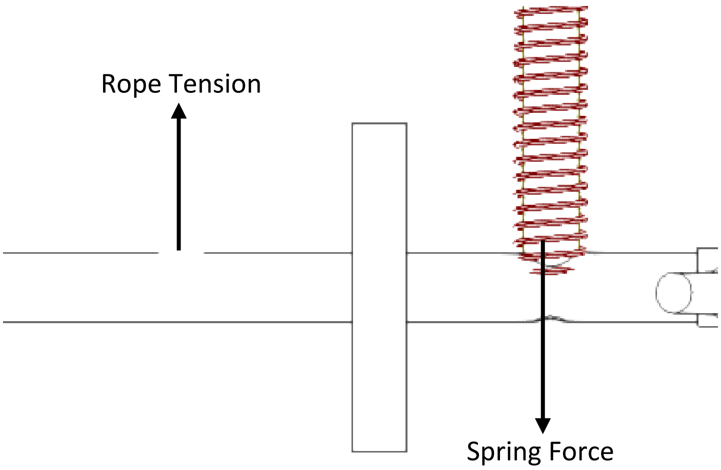
Given the design for the frame, only one concept worth documenting was proposed for retrieval of the mechanism. This concept involved the use of removable shims before the nut on each frame. These shims would be connected to a string. On pulling the string, the shims could be removed, relaxing the spring tension in the frame. Due to the reduction in normal force, the frames would no longer support their weight and would slide down.

Analysis and Design of Springs

Springs form the major functional backbone of the proposed design. Thus, design and iteration was performed on springs to find optimal stiffness and dimensions.

- **Vertical Springs**

  In order to obtain the required stiffness of the vertical springs, a human factors and ergonomics analysis was performed on the force that could be comfortably applied by a user.



It was obtained that a user could comfortably apply a pulling force of about 50-60N in an upright posture while standing at a fixed point and pulling with strokes of 10-12cm length.

Assuming that the spring force is completely balanced out by a 50N human force at 10cm compression in the spring, we obtain a total spring stiffness value of 500N/m.

Since three springs are used in parallel to improve stability of the design, each spring must have a spring stiffness of ~166N/m.

Using standard spring design practices, the design parameters of the vertical springs were set as

Outer diameter: 25mm

Wire Diameter: 2mm

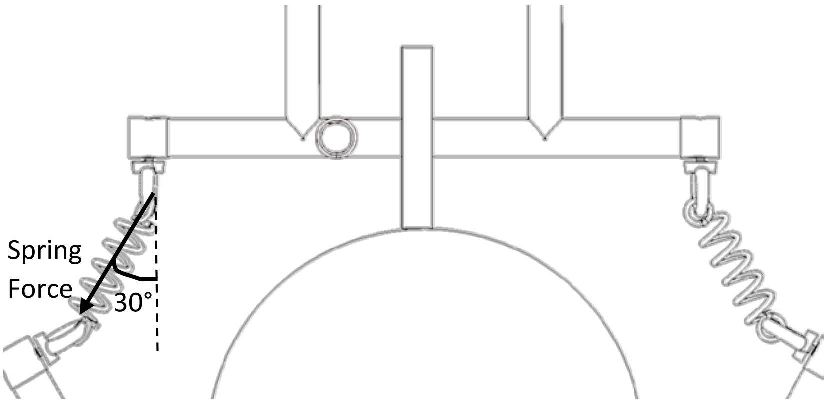
Number of turns: 50

Natural Length: 30cm

- **Tension Springs**

  For design of tension springs, the vertical springs very considered rigid and then the net downward force was taken and equated to the total frictional force generated by the tension springs.

  Net Downward Force = Tension + Frame Weight =~200N



Total Normal Force against tree trunk = 6 * Spring force * 2 * Cos (30)

= 10.39 * Spring Force

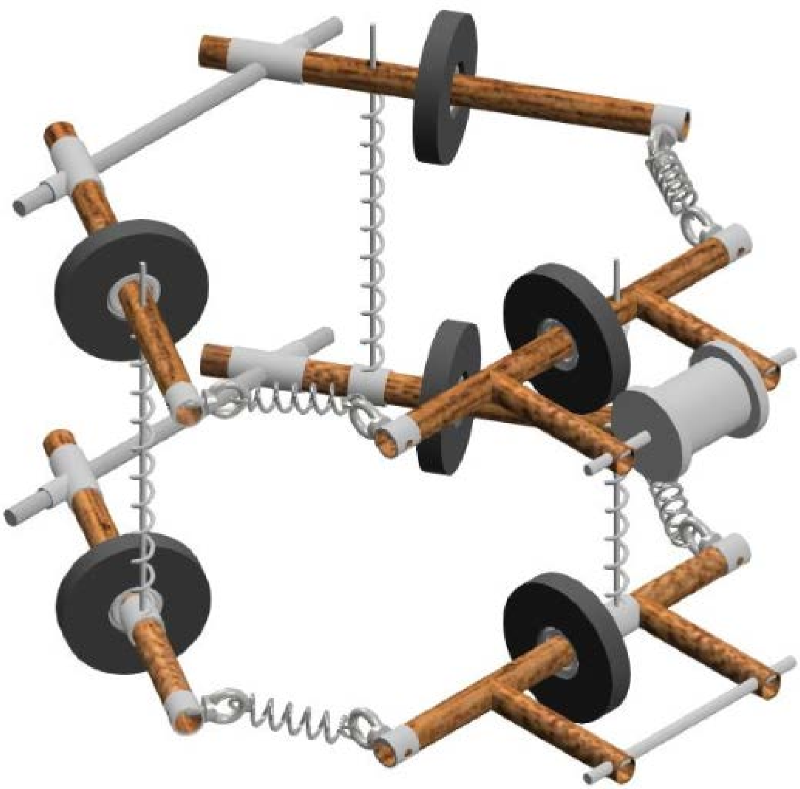
Then, assuming an average coefficient of friction of 0.5 between the tree and the roller, the spring force was estimated to be ~40N.
The diameter range expected for the trees is between 15 and 20 cm. Thus, it necessary that the springs provide at least 40N force at elongation corresponding to a 15cm diameter tree. Also, for a tree of diameter 20cm, the force generated by the spring must not be so high that a user cannot deploy the mechanism on a tree. This upper limit of force was taken to be 75N. Under these assumptions, the CAD models developed beforehand were used to fix the natural spring length at 7cm and stiffness at 105N/m.
The designed parameters were
Outer diameter: 25mm
Wire Diameter: 2mm
Number of turns: 30

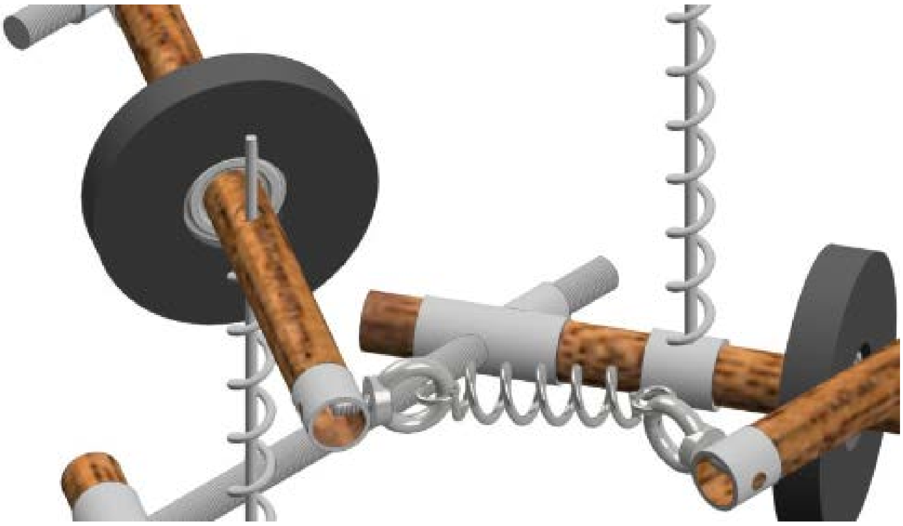
Material Selection and Packaging

- A number of materials were analysed for use in the main frame of the mechanism
  - Steel
    - Advantages: High strength, easy availability, good manufacturability
    - Disadvantages: High weight, moderately high cost
  - Plastics
    - Advantages: Low cost, easy availability, good manufacturability, low weight
    - Disadvantages: Low strength

- Bamboo
  - Advantages: Low weight, high strength, moderate cost
  - Disadvantages: poor manufacturability and availability
- Though bamboo is mechanically the most appropriate material to build the final product, it is not ideal to build a prototype due to its poor manufacturability. A prototype may be built in a way that it can be modified easily, cheaply and quickly to accommodate design iterations, which is not feasible with bamboo.
- Thus, a plastic (PVC tubing specifically) construction was chosen for the prototype.
- During final design iterations, two improvements to the overall assembly were implemented
  - A slider tube was placed inside the vertical springs to prevent buckling.
  - The ratchet was placed in the same axis as the man frame tubing to further improve design compactness

CAD Designs





Prototype

Current Issues/Potential Improvements

- **Unwanted flexure/Misalignment**
  Due to errors in manufacturing, some components in the current prototype are not properly aligned. This leads to unwanted deformation in some components when the prototype is assembled. This can be improved using better manufacturing methods.
- **Frictional resistances**
  During its operation, the prototype suffers fiction from the sliders introduced to prevent spring buckling, as well within the ratchets themselves. Both these resistances are much greater than initially estimated during design and greatly hinder the motion of the prototype.
- **Imbalance under user force**
  As the input force from the user is provided only to one side of the frame, this creates significant imbalance in the system, leading to unexpected deformations in the entire system
- **Proposed improvement: User adjustable normal force**
  One of the most critical requirements to the operation of the mechanism is the application of the correct amount of normal force against the tree so that sliding of the wheels is prevented, yet minimal resistance is provided to rolling. This is very hard to achieve practically. Therefore, the addition of a device that allows variable normal force would be greatly beneficial to the performance of the prototype. When a part of the frame is to be fixed, normal force can be increased, while when it is supposed to move, the normal force can be reduced to reduce rolling resistance.

References

- Human Performance Capabilities
  - Man-Systems Integration Standards, NASA
- Spring Design and Manufacture (Workshop Practice)
  - Cain, T.