Project I—Toy Design

ENSC 386 Spring 2016

3/2/2016

Jesse Kazemir
301227704
jkazemir@sfu.ca

Eva Liu
301243938
wenyul@sfu.ca

Contents

Introduction

In this project, we analyze and reproduce the motions of a wind up mechanical toy. We will choose which three features we want to focus on, and create three distinct designs for each feature. Then we will choose the best design for each feature based on advantages and disadvantages of each design, and combine them into one design that implements all three features with one input.

In our group, we have two members: Jesse Kazemir and Eva Liu. Both members contributed equally to complete the project.

1. Jesse Kazemir :
    - SolidWorks Modeling
    - Linkage analysis
    - Rough Paper Designs of Features
    - Report
2. Eva Liu:
    - SolidWorks Modeling
    - Rough Paper Designs of Features
    - Patent Research
    - Report

The toy we were assigned was the mechanical dog. The dog stands on its hind legs, which rotate back and forth. This causes the rest of the dog to stand up and lay down. The front legs and the head both rotate up and down, with about four times the frequency of the back legs. The tail of the dog also spins very quickly. Of the four motions the toy produces, we chose the following three to be our features:

1. Spinning Tail
2. Leg/Body Motion
3. Head Motion

As the only output motion in our features is rotary (about a pivot) instead of following a path, we were unable to use WATT to synthesize any of our designs.

Putting aside the different frequencies of each feature (which can be trivially changed with gear ratios), we have two basic mechanical assemblies to design. The first, for feature 1, is a construction that converts the direction of rotation from the input to the tail, which are at a 90° angle to one another. The second mechanical assembly is the same for features 2 and 3, as both features an oscillatory rotational motion about a pivot.

Feature Design

- ## Feature 1: Spinning Tail

For the rotation transformation, different gears can easily complete the motion. Bevel gears and helical gears both will change the rotation by 90-degree. Besides gears, universal joints also allow the transmission of rotation in a certain angle. Table 1 shows the three different designs we finally decided, and analysis of each design. Note the circles represent the pitch circle of a standard gear.

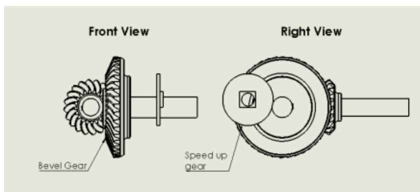
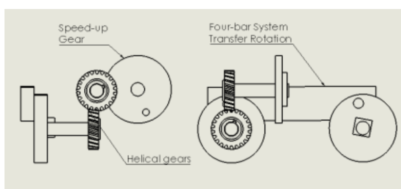
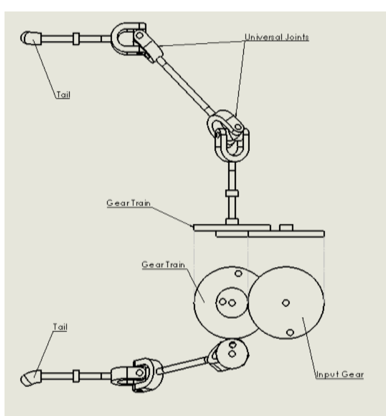
Design	CAD Diagram	Advantages	Disadvantages
1) Bevel Gears and Axles		The speed and torque of driven gear can be varied by changing the gear ratio	Requires precise mounting
2) Helical Gears and 4-bar Mechanism (Instead of using axles, a parallel 4-bar mechanism is used to transfer angular displacement)		It can transfer motion and energy in either parallel or perpendicular angle. The angled teeth can run more smoothly and quietly than others.	Helical gears are not efficient Generates axial forces Requires precise mounting
3) Universal Joints		Allows transmission of rotation for a range of angles Can transfer both torque and motion Does not need to be precisely mounted	Complex topology Many moving parts Angular velocity can be non-uniform depending on joint angles

Table 1

- ### Feature 2: Leg/Body Motion

The leg pushes the whole body up and down. In this feature, the mechanism needs to convert rotational motion to oscillatory rotational motion about a pivot. The three designs we came up with are shown in table 2. The easiest way of doing this is to first convert the rotational motion to oscillatory linear motion. The linear motion can then be transferred to an actuating element mounted on a pivot. Designs 1 and 3 implement this concept.

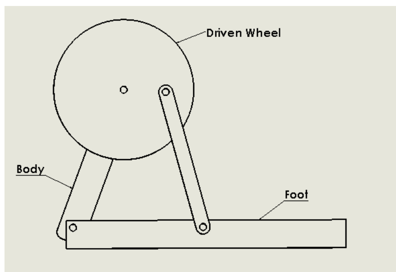
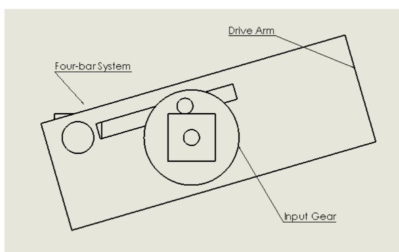
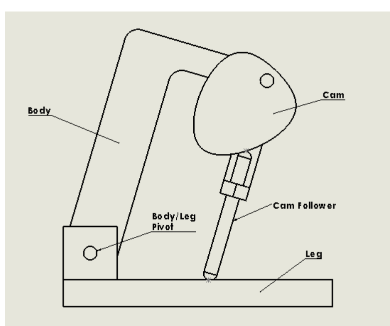
Design	CAD Diagram	Advantages	Disadvantages
1) Four-Bar Linkage		Easy to build Output angle can be easily varied by adjusting the lengths of the links Able to transfer high torque	Motion may be slightly faster in one direction
2) Quick Return Mechanism		Simple topology	A large foot is needed to give enough clearance to the wheel Motion is much faster in one direction Friction from sliding element
3) Cam and Follower		Can produce any repeating motion function	Manufacturing cam is expensive Unable to operate at high speeds Friction from sliding cam follower

Table 2

- ## Feature 3: Head Motion

Similar to feature 2, the head going up and down is also an oscillatory rotational motion about a pivot. Our three designs are shown in table 3. Designs 2 and 3 both make use of the same method as designs 1 and 3 did for feature 2 - first converting the rotational motion into linear motion, and then using that linear motion to drive an actuating element mounted on a pivot. Note in design two, the circles represent the pitch circles of gears.

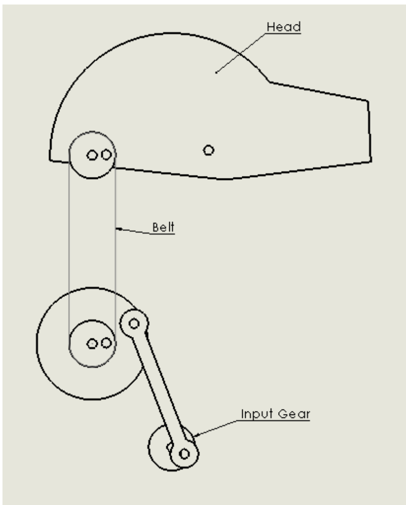
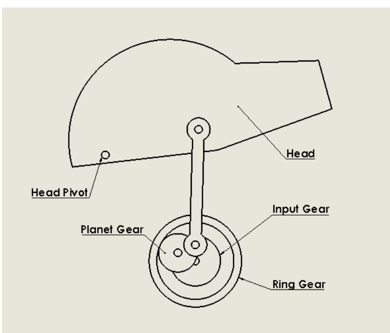
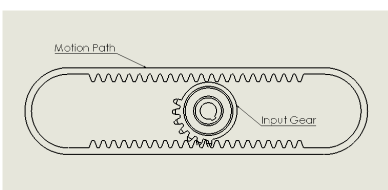
Design	CAD Diagram	Advantages	Disadvantages
1) 4-bar Linkage and Belt		Relative size of gears can be easily varied to change range of motion Easy to fit around obstacles by varying the belt length and/or wheel locations	Unable to transfer high torque due to belt slippage and gear ratio
2) Cardan Gear		Small assembly Easy to calculate the path of head. Strong structure	Requires a second joint on the head Hard to mount gears securely
3) Reciprocating Rack and Pinion		Easy to locate each part of the system.	Range of motion only adjustable by designing a new gear set Requires a second joint on the head

Table 3

Patent Search

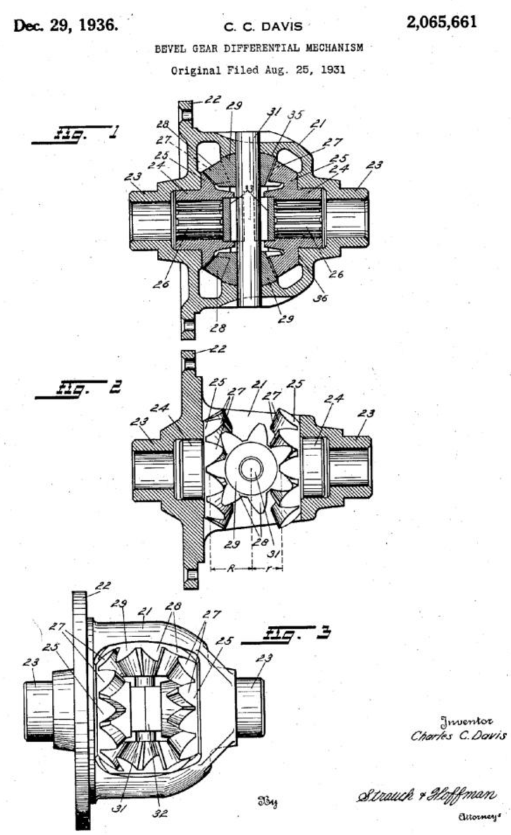
- **Feature 1: Rotation Transformation**

1. Bevel gear differential mechanism (Davis, 1936)

Patent number: US 2065661 A   Publication date: Dec 29, 1936

The patent mainly presents invention to improvements in differential bevel gearing. As showing in the figure, there are four bevel gears which are perpendicular to each other. Due to the specific function of bevel gear, we use this in our feature 1 design as rotation transformation.

This invention is designed for motor vehicles in preventing loss of traction when one of a set of differentially driven wheels slips in a single axle, thereby increasing the tire lifetime and safety of vehicles.

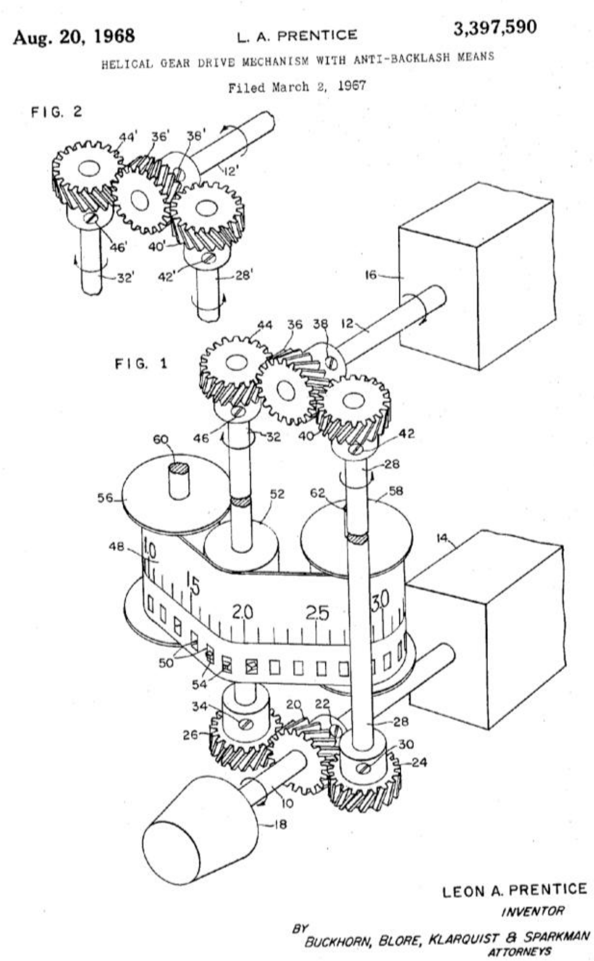


2. Helical gear drive mechanism with anti-backlash means (A, 1968)

Patent Number: US 3397590 A Publication Date: Aug 20, 1968

The patent includes several helical gears to make the rotation changing, which also fits our feature 1 design. This patent also has a gear chain to change the speed of rotation.

The present invention relates to a drive mechanism for driving a pair of shafts in unison and particularly to such a mechanism for driving a pair of spaced shafts where backlash between the shafts is eliminated.



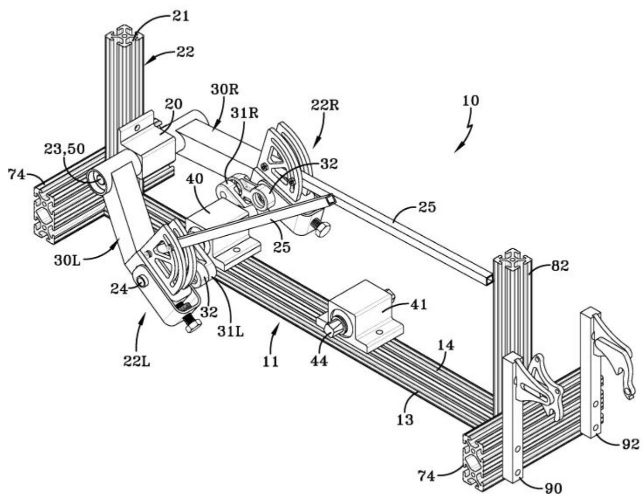
- ## Feature 2: Leg Push-Up

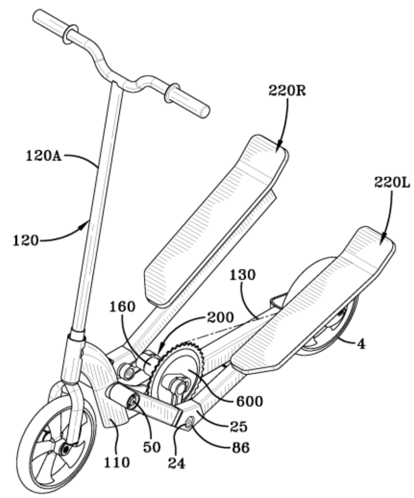
1. Four bar drive link system simulator (Nathan Anthony Scolari, 2014)

Patent Number: US 8622749 B2 Publication Date: Jan 7, 2014

Four-bar mechanism is the most common design. And we can easily find it in many patents. Four-bar system transfers the motion between linear movement and rotation. In order to make the dog leg pushing up, we need to change the source rotation to linear motion.

This patent uses the foot push as input movement, by using four-bar drive linkage, transfers this motion to the wheel's rotation.





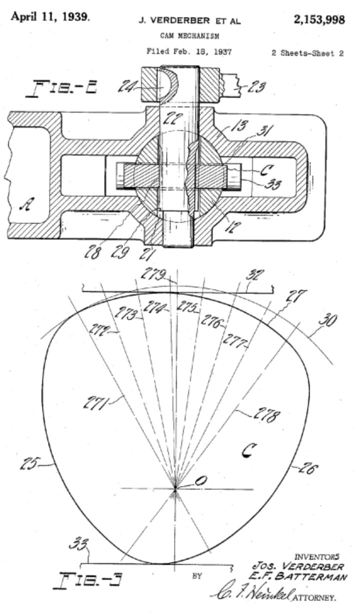
FIG−6

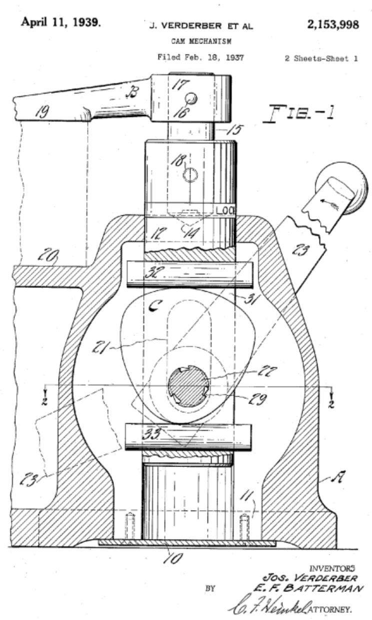
2. Cam Mechanism (Batterman Elmer F, 1939)

Patent Number: US 2153998 A Publication Date: Apr 11, 1939

A cam mechanism moves an element into a position for clamping and clamps the same in that position and locks the same against self reversing by a single rotation movement of a cam.

This patent presents a shape with different radius, by rotating this shape; the upper part can be pushed up and down due to different distance from the edge to the central.





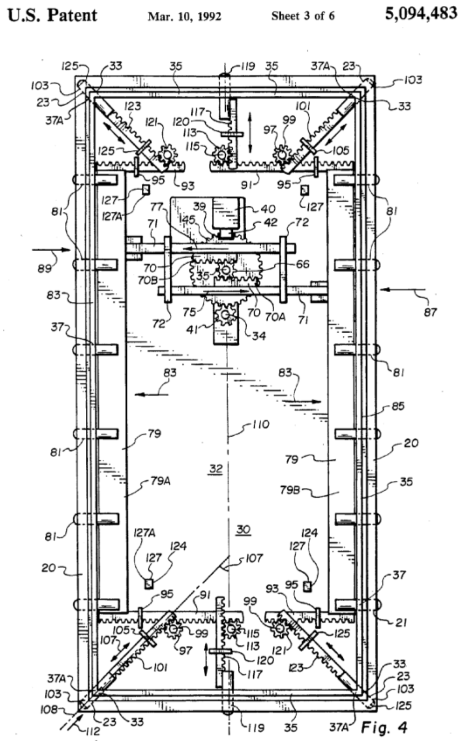
- ## Feature 3: Head Up and Down

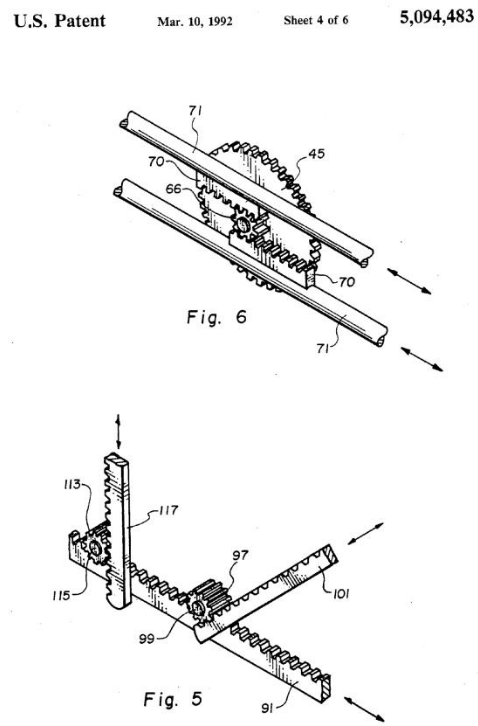
1. Locking mechanism for a safe door (James, 1992)

Patent Number: US 5094483 A Publication Date: Mar 10, 1992

The locking mechanism includes a drive gear which is rotatable mounted on the interior surface of the door. A drive means, mechanically associated with the drive gear, is adapted for permitting the safe's user to rotate the drive gear from the door's exterior surface.

This patent chose teeth designed on the gear and straight path and the combine the motion of both getting the changing of motion, which is the source of our reciprocate system design



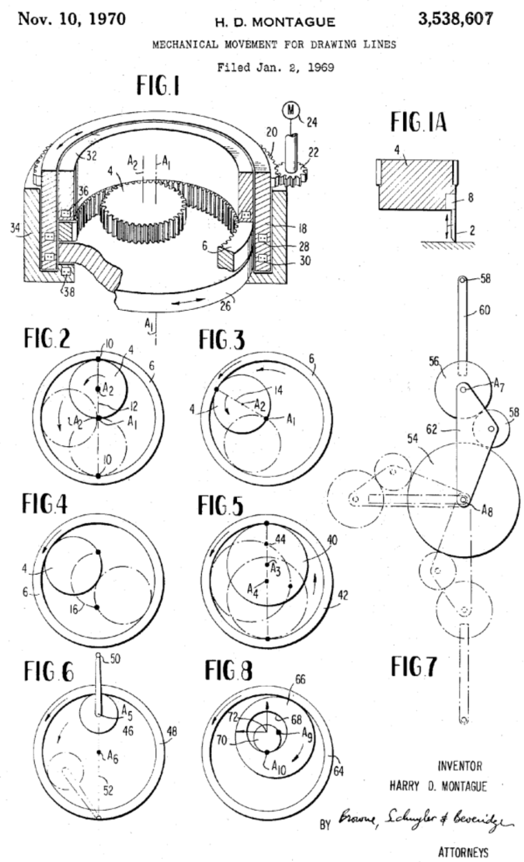


2. Mechanical movement for drawing lines (D, 1970)

Patent Number: US 3538607 A   Publication Date: Nov 10, 1970

This invention relates to a mechanism which employs a pair of operatively engaged gears for producing linear movement of a working element.

The well known principle of Cardan gearing is used for producing linear movement with a pair of operatively engaged gears.



Nov. 10, 1970
H. D. MONTAGUE
3,538,607
MECHANICAL MOVEMENT FOR DRAWING LINES
Filed Jan. 2, 1969
FIG.1
FIG.1A
FIG.2
FIG.3
FIG.4
FIG.5
FIG.6
FIG.8
FIG.7
INVENTOR
HARRY D. MONTAGUE
BY Browne, Schuyler & Beveridge
ATTORNEYS

Chosen Designs and Size Analysis

- ### Feature 1: Spinning Tail

For this feature, we decided to choose design 3 - universal joints. Universal joints have several moving parts (which complicates fabrication) but they are very forgiving when it comes to design changes and precision errors. A universal joint chain like the one shown will still be able to fit and function if the tail mount is moved slightly, for a design change or as a result of an error in manufacturing. The other disadvantage of universal joints (that the angular velocity may not be uniform) is not an issue here, as the rotation is purely cosmetic. Additionally, the relatively fast rotation of the tail will make a non-uniform angular velocity hardly noticeable, if noticeable at all.

Designs 1 and 2 would have worked as well, but they have some disadvantages. Both designs have gears, which require precise mounting. This makes manufacturing more difficult. The bevel gears also require more space for the linkage to rotate around in than an axle would.

The dimensions of this feature are not very important. We based all measurements off of a 1 cm diameter axle (for convenience). The size of the universal joints themselves is arbitrary, as long as they fit in the body. As for the speed, we used two 12:5 gear ratios (resulting in a 144:25 gear ratio overall) in our combined design. The tail rotates roughly six times for every rotation of the input. This exact value was chosen somewhat arbitrarily, and could easily be increased or decreased to change the relative speed of the tail, if a specific angular velocity was desired.

- ### Feature 2: Leg/Body Motion

Design 1 (4-bar linkage) was chosen for this feature. This design is easy to build, easy to modify for a specific output range, and can provide high torque. Since this feature is lifting the rest of the body and the other mechanisms, it is important that this feature can operate under load. The main disadvantage of the design is that the motion can sometimes be slightly faster in one direction. Although this problem can be fixed by strategically placing the link pivots, this non-uniformity is minimal and we decided it was acceptable.

We didn’t choose design 2 because it obstructed the leg element too much, and we decided against design 3 because, although we could get whatever rotation function we wanted, the design would be complicated to build and would lead to a lot of friction. The low-speed restriction on design 3 was not a factor in our decision, as this feature is the slowest of the three.

The sizing of this linkage is chosen to get a range of motion of roughly 45° between the body and the leg element. The link lengths and joint locations can easily be altered to get a different angle range if a specific angle is important. We observed the period of this oscillation to be four times that of the head motion, so a gear ratio of 1:4 is used. For this feature to go through it is full range of motion once, it takes four turns of the input.

- ### Feature 3: Head Motion

For this feature, we selected design 1 - 4-bar linkage and belt. This design has the huge advantage that the main mechanism can be positioned anywhere in the body, pivoting the head remotely via the belt. This allows for significant design flexibility. This design also does not require a second joint on the head element, which leaves the exterior clean. The only disadvantage of this design is the low-torque restriction due to limited belt friction and the small radius of the driving belt. However, this feature only drives the head (which can easily be made light) and the torque needed will be minimal.

Designs 2 and 3 would also work to create the motion needed, but they both are quite complex and require specially manufactured parts. Additionally, design 3 would have a potential problem with the point in time where it disengages with the left teeth and engages with the right teeth (and vice versa). Because it would be actuating vertically, the weight may cause it to fall/slip downwards if it were not designed perfectly.

This feature was designed to have a range of motion of roughly 30°. This can be changed very easily by varying almost any of the parameters. However, it is probably easiest way to vary the relative sizes of the two belt wheels. This feature has a gear ratio of 1:1, so it completes one revolution every time the input does.

Assembled Design

In our design, the input drives the spinning tail (feature 1) through a gear train and universal joints. There are two pairs of 12 cm and 5 cm gears connected to speed up the input rotation. A gear of diameter 12 cm is fixed on the input axle, which is meshed to a gear with a 5cm diameter. This 5cm gear is fixed to a second gear of 12 cm on the same axle. This second 12cm gear is then meshed to a second 5cm gear on the universal joint shaft. This gear train speeds up the rotation by a factor of 144/25, or by roughly six times. After the gear chain, the universal joints convert the direction of rotation to rotate the tail. (Figure 1)

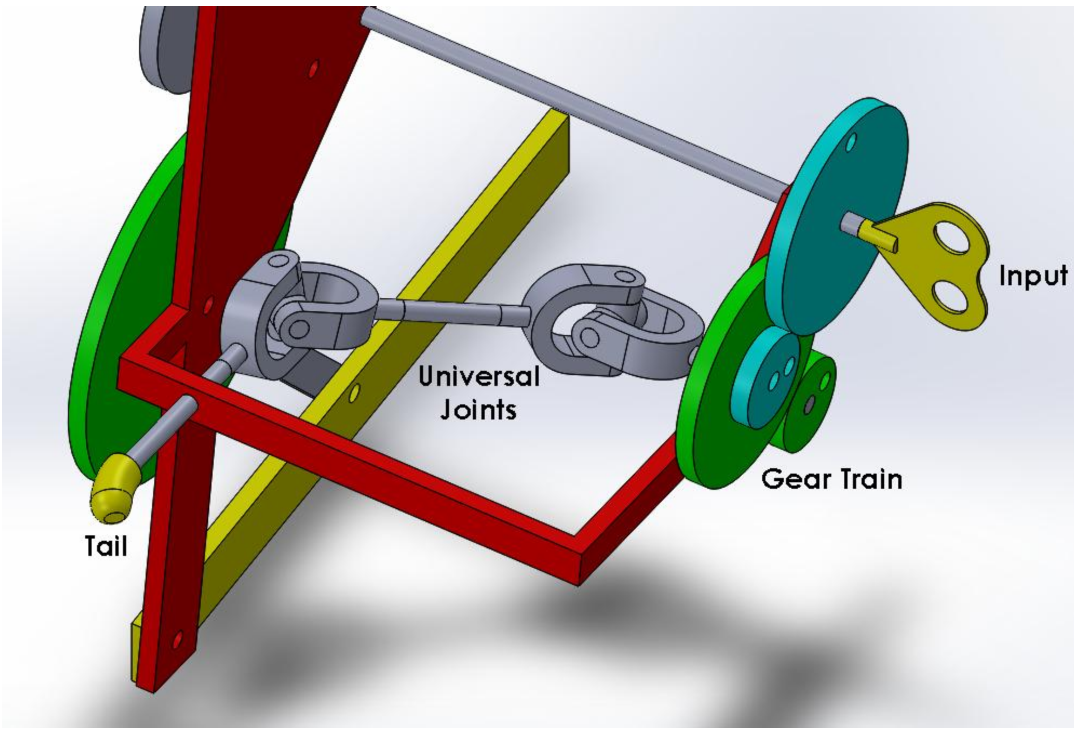


Figure 1

Red: body   Yellow: input/output   Green/blue: meshing gears

The head mechanism is also driven directly by the input shaft. There is a gear with a 5cm diameter on the end of the input shaft that is meshed to the input gear of the head assembly (the gear with a link connected to the belt wheels). The rotation of this gear causes the belt wheels to oscillate, which causes the head to do the same. This feature is not geared at all, so one revolution of the input causes one complete cycle of the head movement. (Figure 2)

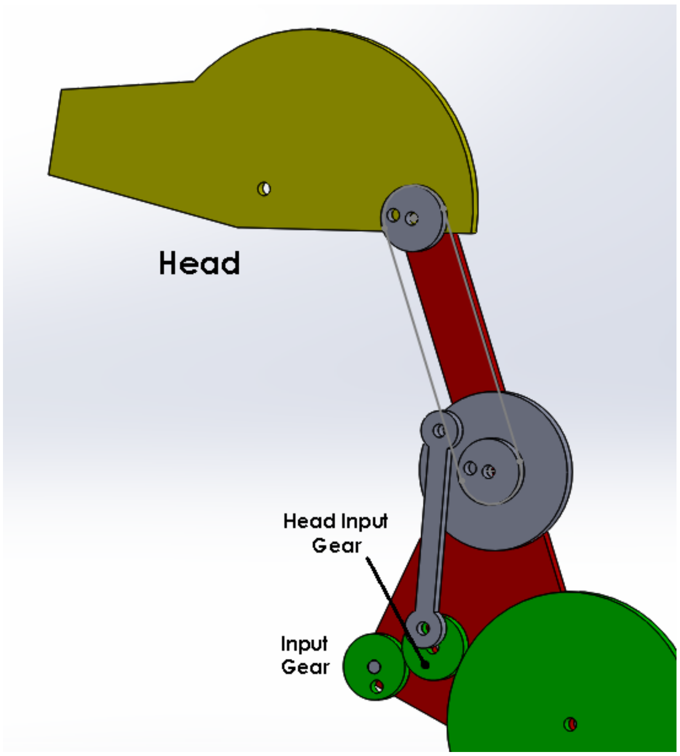


Figure 2

Red: body Yellow: input/output Green/blue: meshing gears

For the body movement, there is a simpler four-bar system to complete the transformation. The 20 cm diameter input gear to the leg/body mechanism is driven by the 5cm diameter input gear of the head mechanism. This creates a gear ratio of 1:4, meaning the foot/body mechanism will go through a complete cycle every four turns of the head mechanism, or four turns of the input. A bar attached to both the gear and the fixed leg pushes the whole body up and down during the rotation of input gear. If this mechanism was built, a relatively strong material should be used to build this feature in order to hold the mass of the toy. (Figure 3)

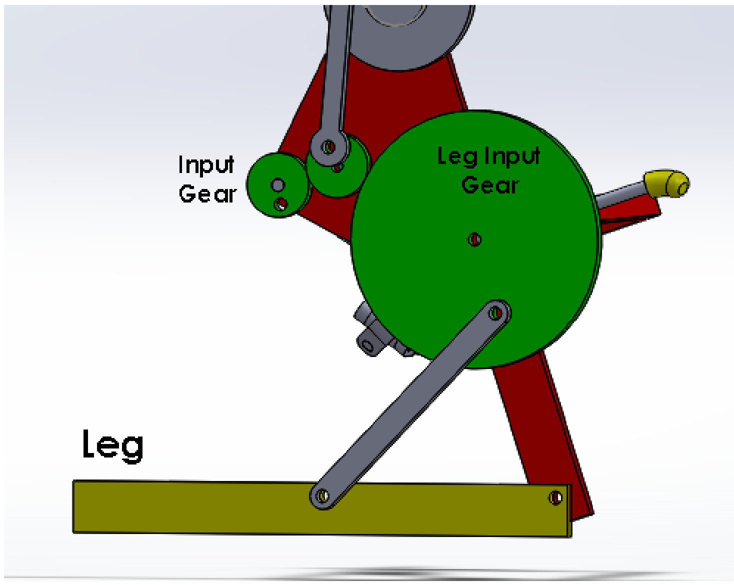


Figure 3

Red: body Yellow: input/output Green/blue: meshing gears

Discussion/Conclusion

By considering modeling cost, design flexibility, loading and structure of the different mechanisms, we decided to choose universal joints and two kinds of four-bar linkage systems to complete our final design, which will meet all the requirements in a simple way. Our design replicates the mechanical dog's movements very closely, and is easily modified to adjust parameters. All of the parts could be modified to fit in a smaller area if needed, and relative positions can easily be changed. It would also be very easy to add in the fourth feature (front leg movement) as it is exactly the same as (and in phase with) the head movement. A second belt and pulley system could be connected to the same wheel as the head belt with minimal alterations to the design.

However, we cannot deny that bevel and helical gears have smaller occupancy and simpler structure that have advantages for large scale manufacturing. The cam system makes allows for a controllable path of output, which would be advantageous, especially if a more non-sinusoidal output function was desired. In addition, cardan gears and quick-return systems could also be advantageous for different motion.

References

A, P. L. (1968). *Patent No. US 3397590 A.* United States of America.

Batterman Elmer F, J. V. (1939). *Patent No. US2153998 A.* United States of America.

D, M. H. (1970). *Patent No. US3538607 A.* United States of America.

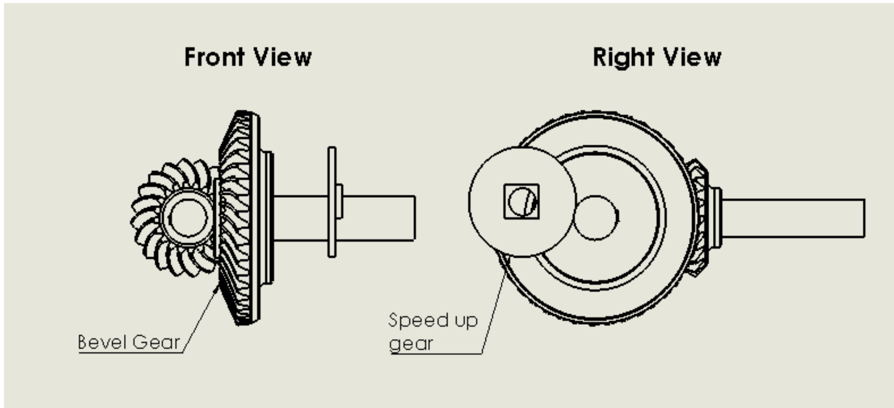
Davis, C. C. (1936). *Patent No. US 2065661 A.* United States of America.

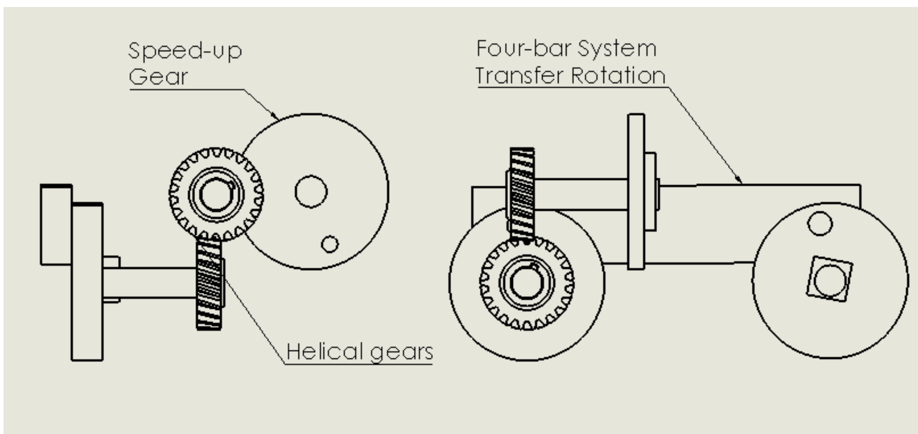
James, C. T. (1992). *Patent No. US 5094483 A.* United States of America.

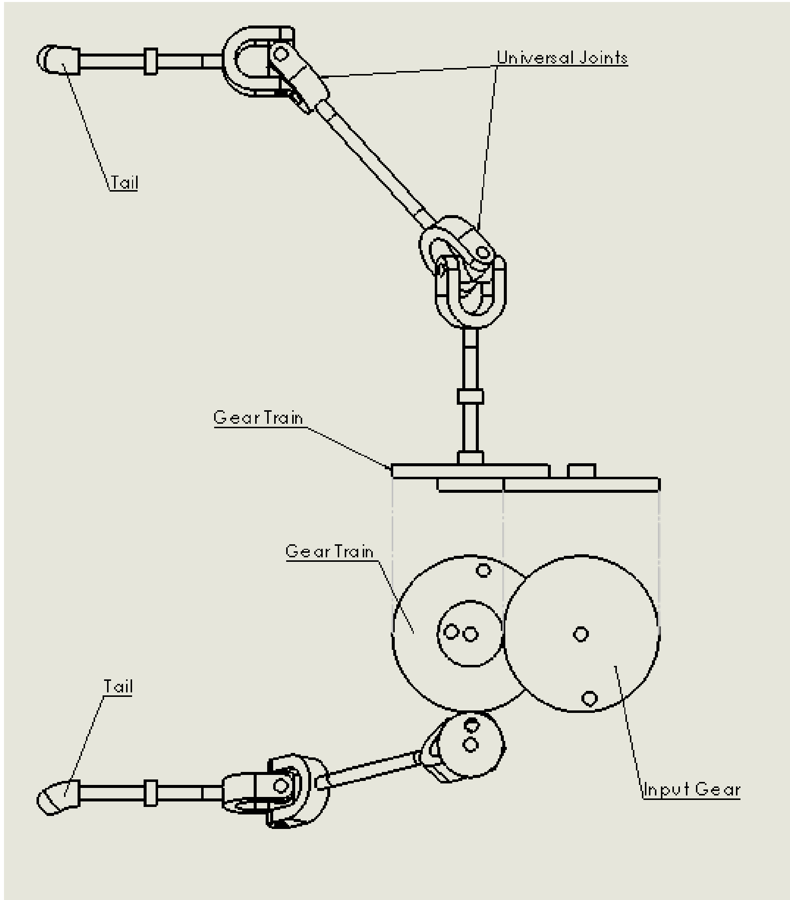
Nathan Anthony Scolari, D. R. (2014). *Patent No. US 8622749 B2.* United States of America.

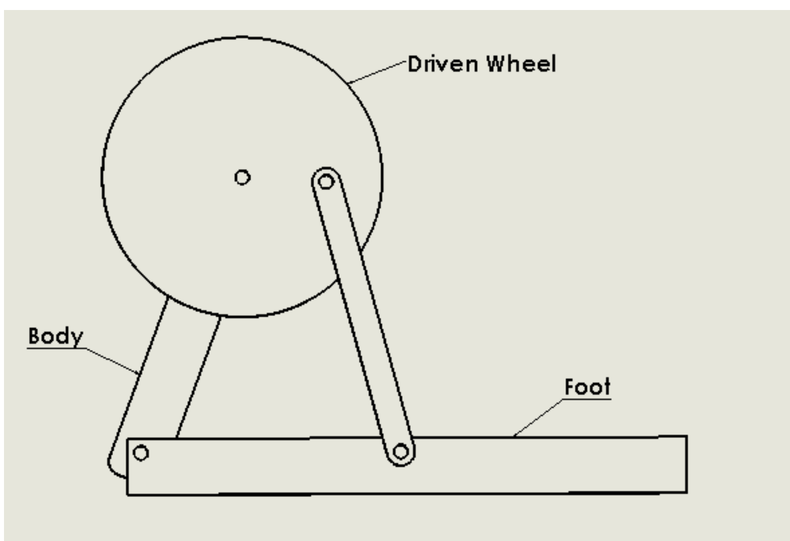
Appendix 1: Solidworks Drawings

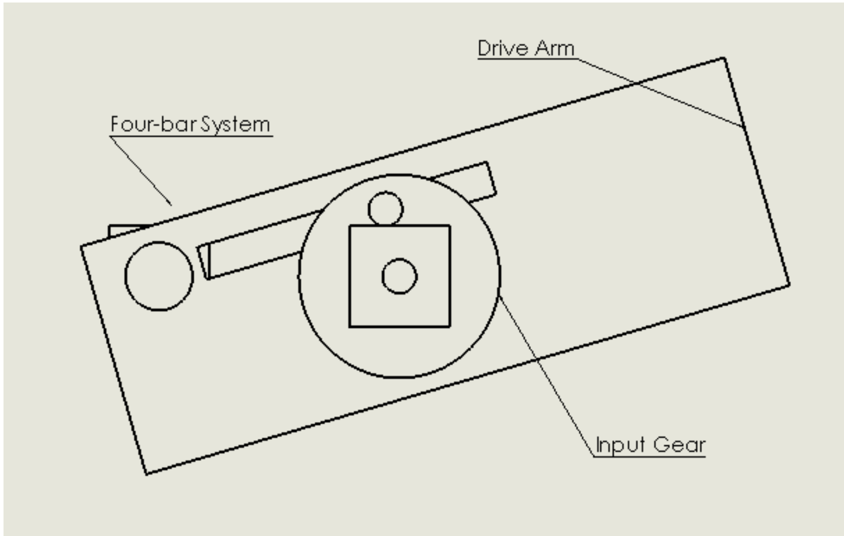
Full-scale Design Drawings



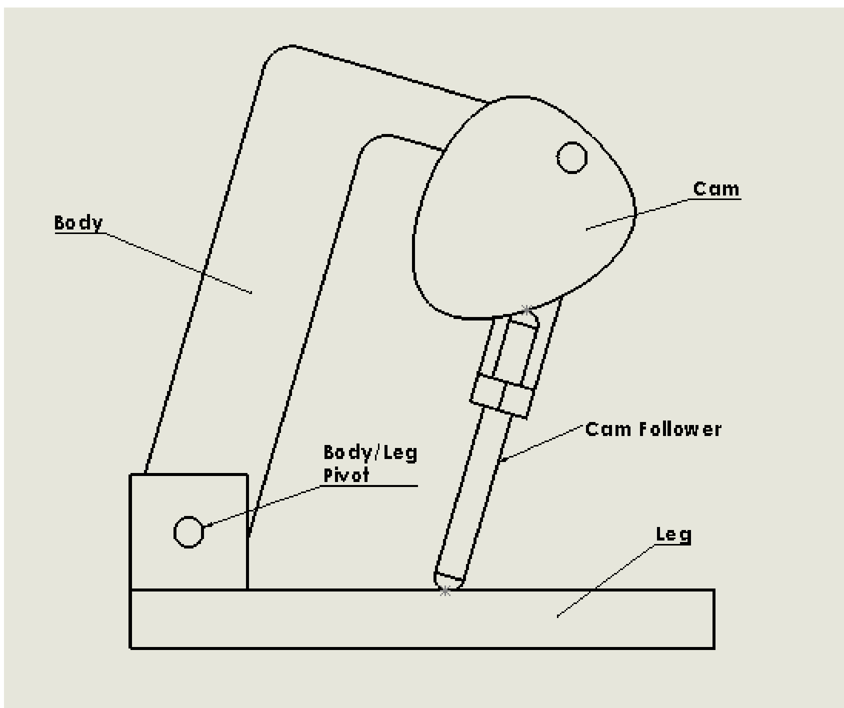



Universal Joints
Tail
Gear Train
Gear Train
Tail
Input Gear

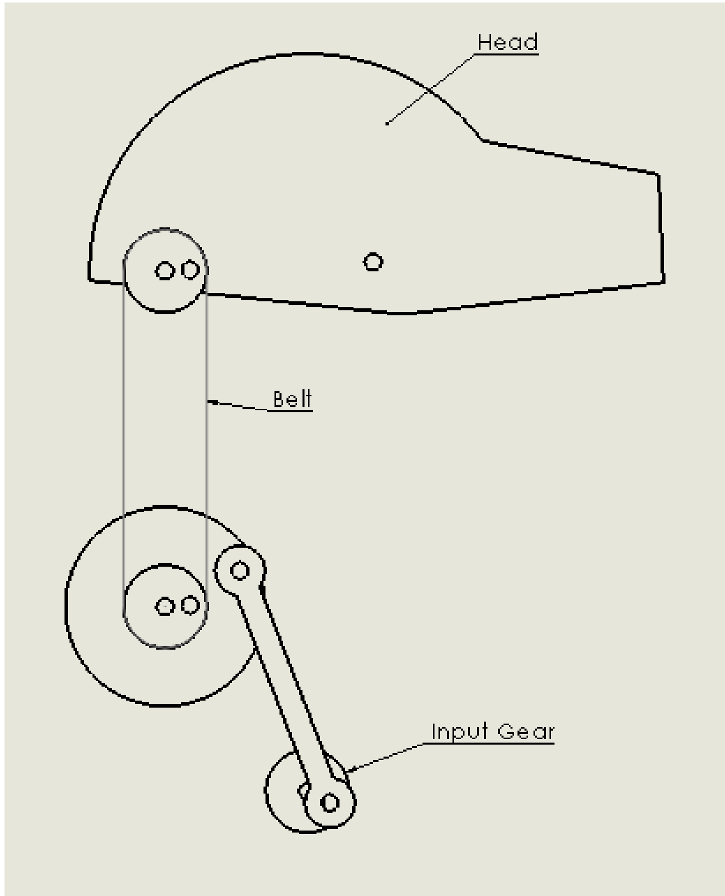

Driven Wheel
Body
Foot

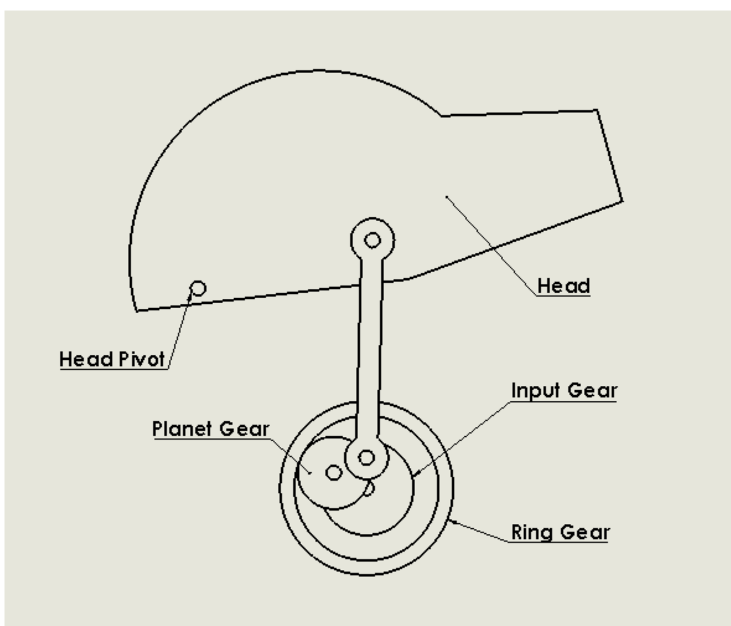


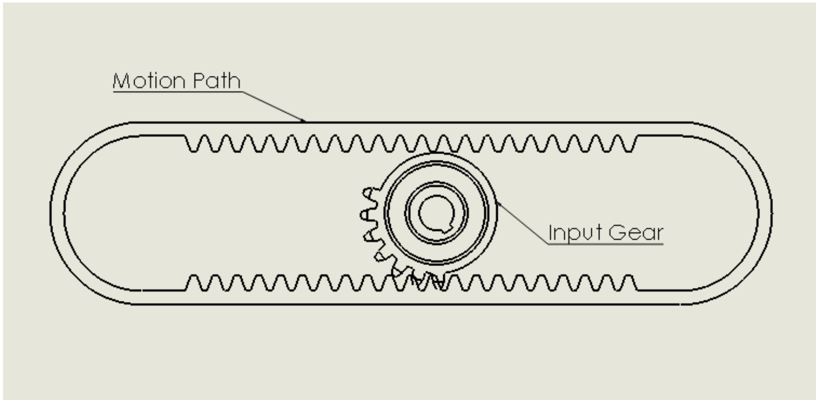
Drive Arm
Four-bar System
Input Gear



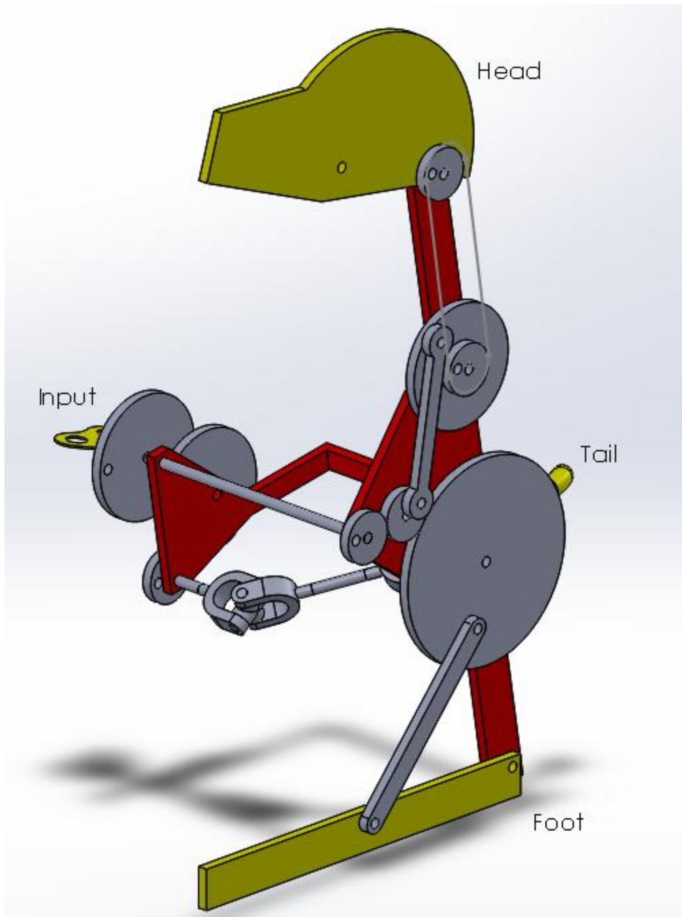
Cam
Body
Cam Follower
Body/Leg
Pivot
Leg


Head
Belt
Input Gear

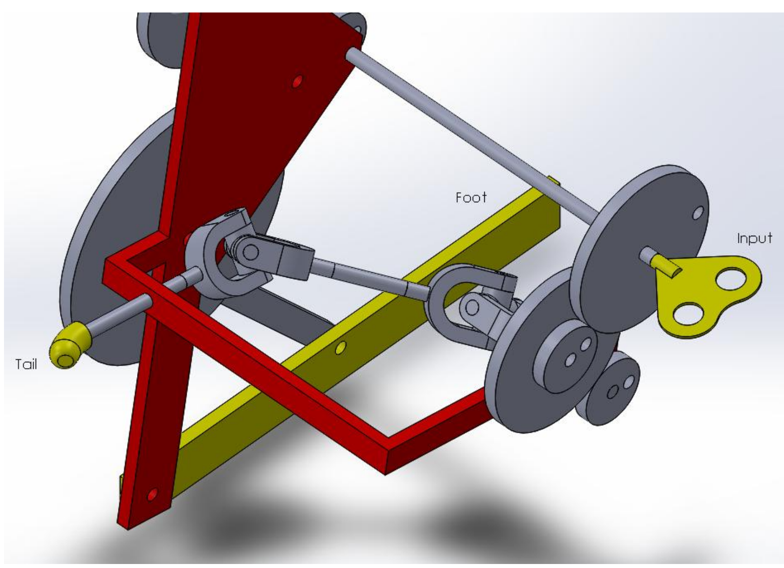

Head
Head Pivot
Input Gear
Planet Gear
Ring Gear


Motion Path
Input Gear

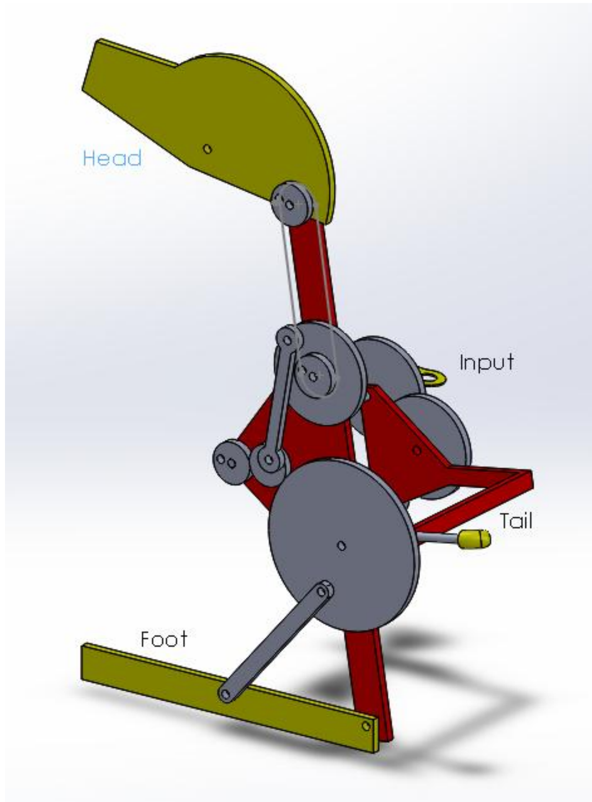
Combined Mechanism



Feature 1: Rotation Transformation

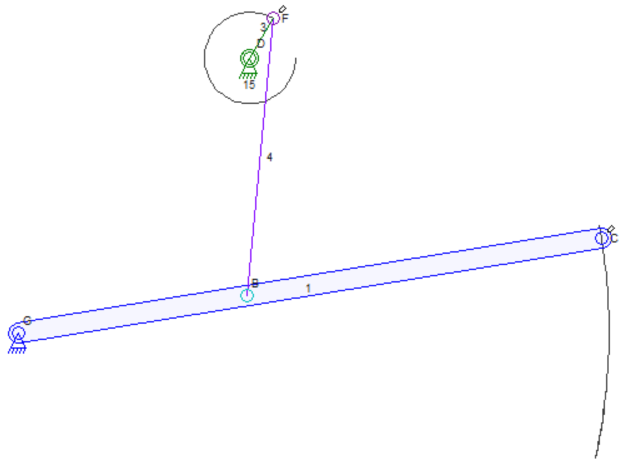


Feature 2 & 3: Leg Push-up and Head Motion



Appendix 2: Linkage Drawings

Feature 2: Leg/Body Movement



Feature 3: Head Movement