OCTAPIED REPORT

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Module 24: Designing a Simple Technical Object
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SUMMARY

When looking at traditional bicycles, I'm thinking about its limitations: We can only ride them on a relatively flat and smooth road. And the bicycle tires, they are made from rubber, which have a fairly low melting temperature point, and can get carbonated by a very hot road surface.

So, I decided to make a human-powered riding machine/vehicle without rubber wheel so that it can run on some extreme conditions (ex: on very rough roads or grasslands or even on some forest paths after a big fire where neither bicycles and vehicles based on rubber tires could not arrive).

As my final project, I decided to build some legs or feet to "walk" instead of using circular wheels.
I happened to see some walking machines as a toy or as a prototype, and I will do some further research on its mechanical relationships so that I can integrate them to my design.

2	x	Circle	→	Bicycle	8	x	Foot	→	Octapied
Bi-		Cycle (en/fr)			Octa-		Pied (fr)		

I named my project as “Octapied”, which has the same word formation as bicycle. It has 8 legs / feet, and is a wheel-less human-powered walking vehicle.

INTRODUCTION

Aim of the Report

This report presents the design for a wheel-less human-powered walking vehicle, including the structure of mechanical sub-systems, their features, mates and materials.

To explain how the walking mechanical legs work, a short chapter of theory is presented in the first chapter of the main part in this report.

Some manufacturing processes are mentioned to the main functional components in order to explain why to choose these raw materials and how to manufacture them.

In order to explain how detail designs and tiny choices were made, some deprecated designs among different features are also mentioned in this report even if they are no longer suggested to use in the final prototype design.

Applicable Scenes

- Rough roads (with some small obstacles like scattered branches after a hurricane or flood)
- Narrow wildland paths (where cars or jeeps cannot get in)
- Hot surface (ex: grassland after a wildfire burning or area of volcanic lava that has not yet fully cooled*)

  * to assure safety, make sure the riding surface of burning area or hardened lava is less than 500°C.[1]
  (6061 Aluminum Alloy's melting temperature is about 585°C.) [2]

Figure 1 Typical applicable scene

THEORETICAL RESEARCH

There are mainly two kinds of successful mechanical walking systems already existed:
Klann Linkage[3] and **Jansen's Linkage**[4]
The Klann mechanism uses six links per leg, whereas the Jansen's linkage developed by Theo Jansen uses eight links per leg, with one degree of freedom (1-DoF).

Klann Linkage (Mechanical Spider)

Klann linkage work on the basis of kinematics where all links gives relative motion with each other. It converts the rotatory motion to linear motion, and looks like an animal walking.

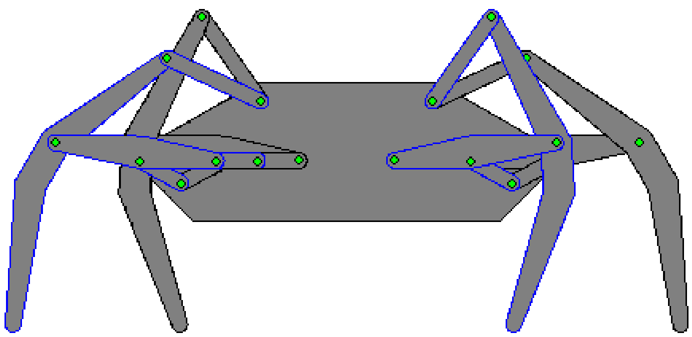


Figure 2 Assembly of a Klann Mechanism

The figure below shows a single linkage in the fully extended, mid-stride, retracted, and lifted positions of the walking cycle. These four figures show the crank (rightmost link in the first figure on the left with the extended pin) in the 0, 90, 180, and 270-degree positions.

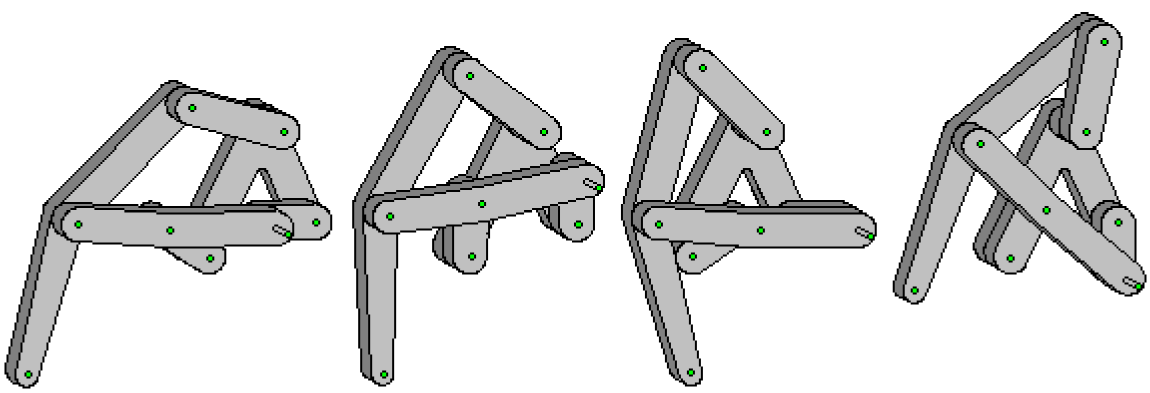


Figure 3 A single Klann Linkage in different positions

Jansen's Linkage (Strandbeest)

Jansen's linkage is a planar leg mechanism designed by Theo Jansen. He has used his mechanism in many kinetic sculptures known as Strandbeest[5].

The central 'crank' link moves in circles as it is actuated by a rotary actuator such as an electric motor. All other links and pin joints are unactuated and move because of the motion imparted by the crank. Their positions and orientations are uniquely defined by specifying the crank angle and hence the mechanism has only one degree of freedom (1-DoF).

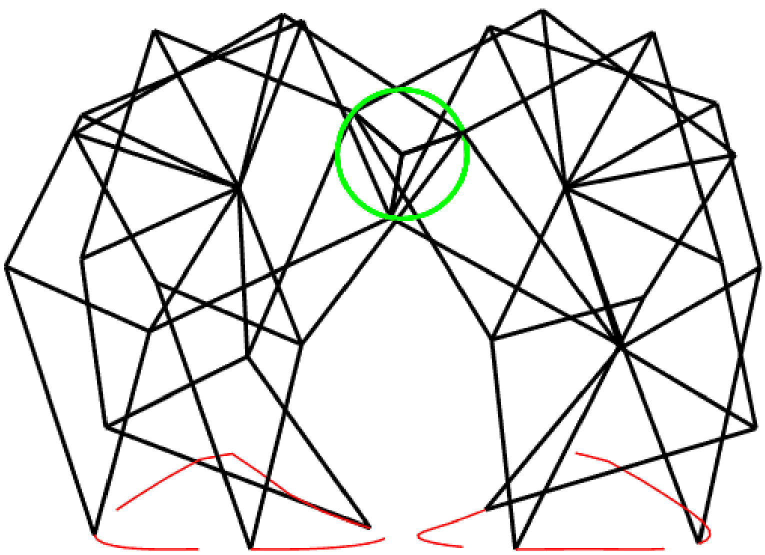


Figure 4 Schematic diagram of a Jansen's Linkage

The figure below shows a single linkage in different positions of the walking cycle.

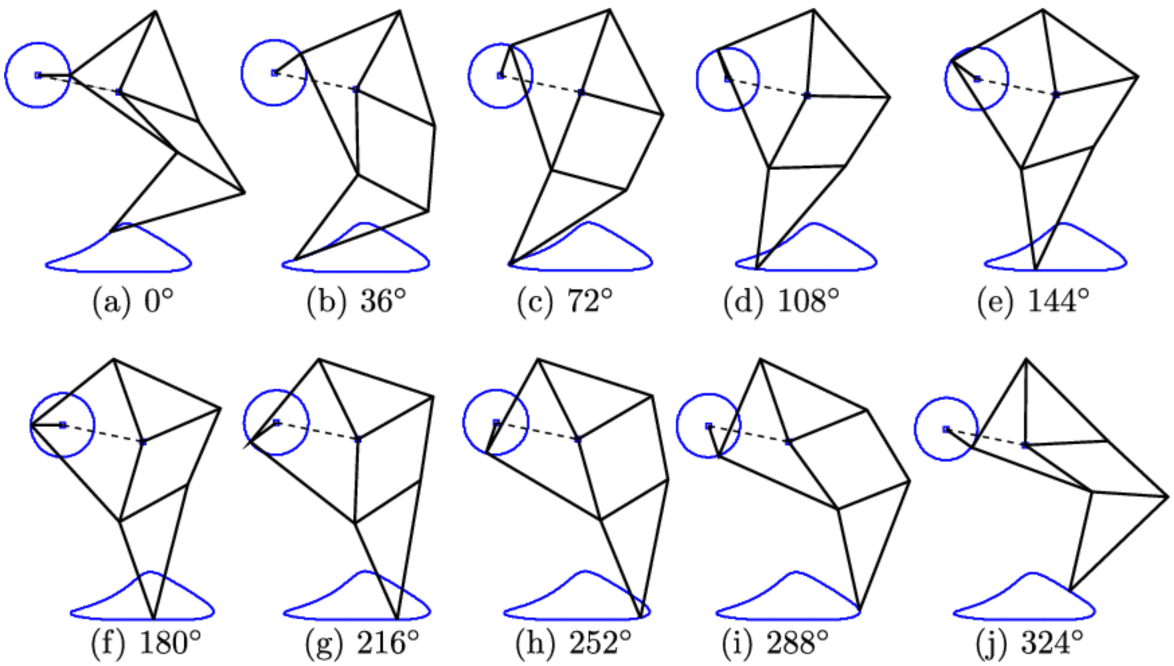


Figure 5 A single Jansen's Linkage in different positions

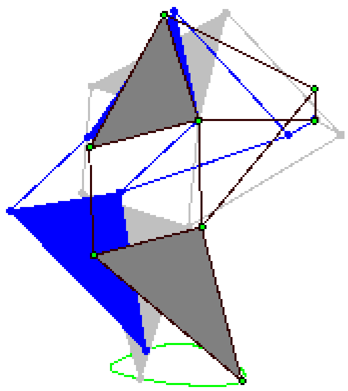
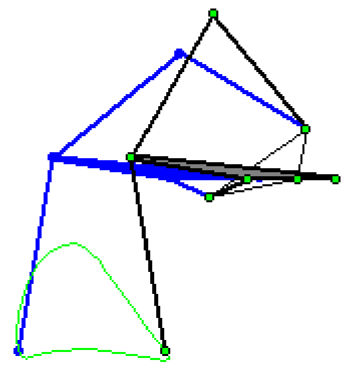
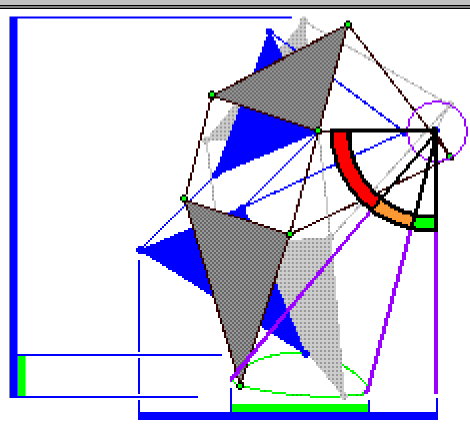
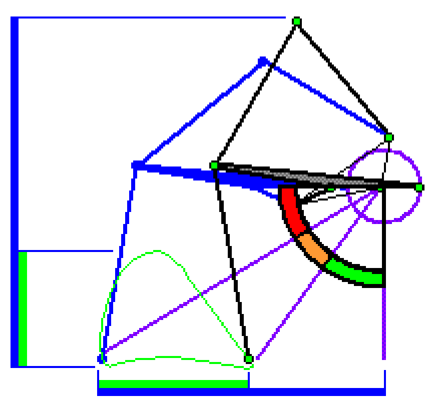
<table>
<tr><th>Jansen Linkage</th><th>Klann Linkage</th></tr>
<tr><td></td><td></td></tr>
<tr><td>8 links per leg
120 degrees of crank rotation per stride.
3 legs will replace a wheel.
Counterclockwise rotation of the crank.</td><td>6 links per leg
180 degrees of crank rotation per stride.
2 legs will replace a wheel.
Clockwise rotation of the crank.</td></tr>
<tr><td>Step height is primarily achieved by a parallel linkage in the leg that is folded during the cycle angling the lower portion of the leg.</td><td>Step height is achieved by rotating the connecting arm which is attached to the crank on one end and the middle of the leg on the other. It pivots on a grounded rocker.</td></tr>
<tr><td>Jansen started in 1990 using computer models to develop a walking linkage.</td><td>Klann started exploring various linkage synthesis methods in 1993 after being inspired in a kinematics class.</td></tr>
<tr><td>The eight-bar Jansen linkage evolved through iterations of a computer program.</td><td>The six-bar Klann linkage is an expansion of the four-bar Burmester linkage developed in 1888 for harbor cranes.</td></tr>
<tr><th colspan="2">Size and Tilt</th></tr>
<tr><td></td><td></td></tr>
<tr><td colspan="2">The step height, stride length, ground clearance, overall size, and maximum incline, as well as the ratios of these factors, are obvious ways to compare the two linkages. Both linkages can be proportioned differently based on the inputs in the relationships. The center of gravity coincided with the center of the crank in the comparison of these linkages’ ability to handle an incline but could be significantly different depending on a wide range of factors.</td></tr>
</table>

Table 1 Comparison between Jansen's Linkage and Klann Linkage[6]

According to Table 1, both Klann Linkage and Jansen's Linkage are suitable for my purpose of project design, I finally choose Jansen's Linkage as my main reference.

Further Research on Legs

The core of a Jansen's Linkage design is the ratio between different legs, once we follow this ratio, no matter what the scale is, the final assembly will work perfectly as a walking leg.

As Figure 4 shown in previous page, a typical Jansen's Linkage will contain at least 3 legs per side. If it's less than 3 legs, the walking action won't be smooth enough, or it will even fall down to the ground.

The red and light-blue triangles in Figure 6 are stable parts in the whole system, all lines in other color are movable.

The two black dots are fixing axis to position the leg.

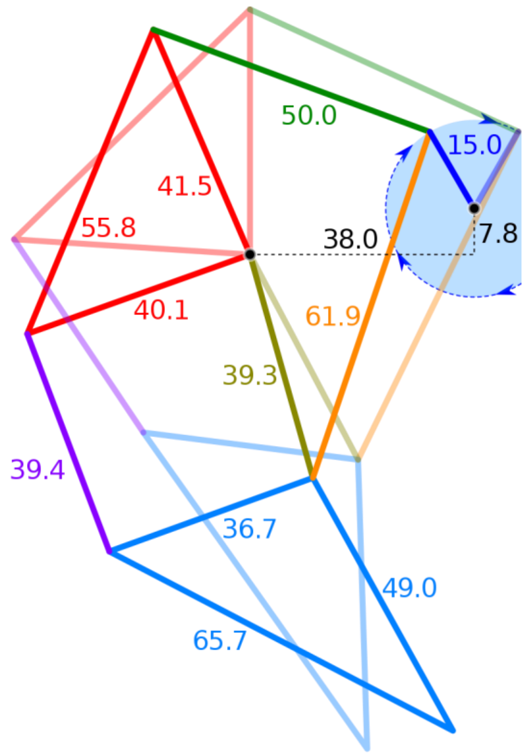


Figure 6 Jansen's Linkage Leg Ratio

The Needs to be Met

To use Jansen's Linkage, one must follow these needs as listed below:

- Leg ratio
- Position of the fixing axis
- At least 3 legs per side

MANUSCRIPT

In the very beginning of a project design, collecting thoughts is very useful. Therefore, when never a good idea pops up in mind, it's necessary to record it by hand drawing rapidly.
Also, during the whole modeling process, calculating on paper is an indispensable method to determine the correct dimensions, for example: Dimension Chains.

Following are some of my manuscripts, they are very helpful to complete my project parts and assemblies as well as this report itself.

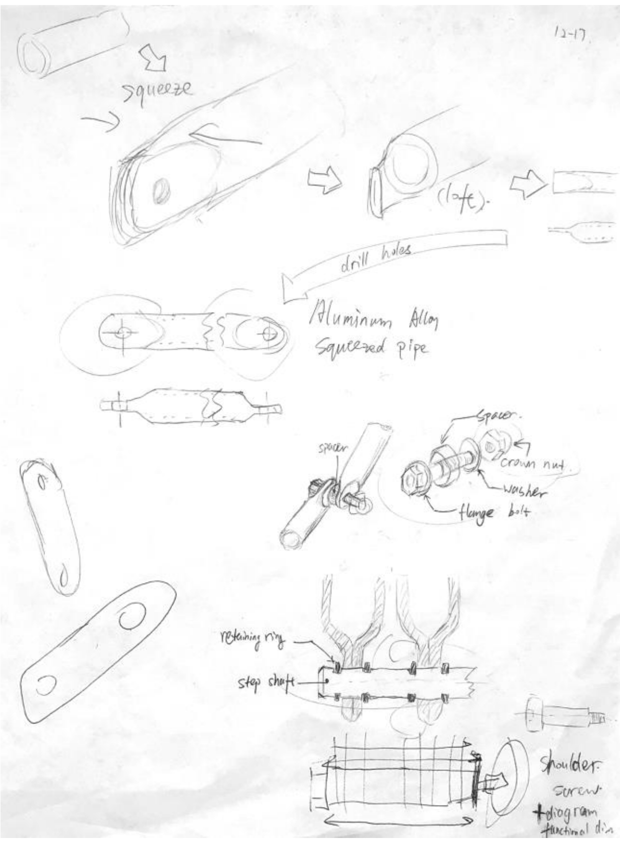


Figure 7 Manuscript for leg pipe prototype

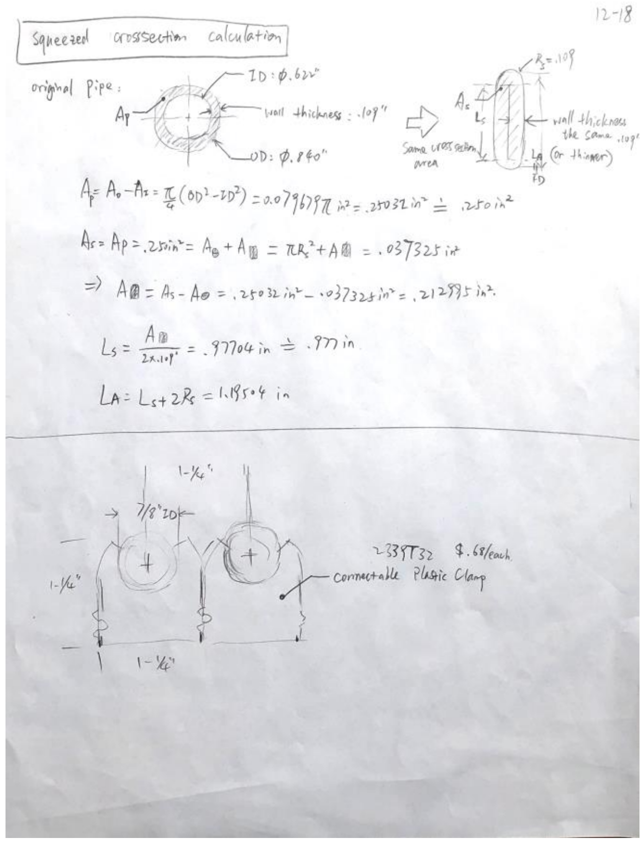


Figure 8 Manuscript for squeezed cross section calculation

Comparing Figure 7 and Figure 8 with Figure 12 (page11) and Figure 13 (page12), we will see how an early manuscript effects.

The two figures below show hand calculation based on a printed paper with some already made parts. Dimension Chain calculation is applied in the right figure.

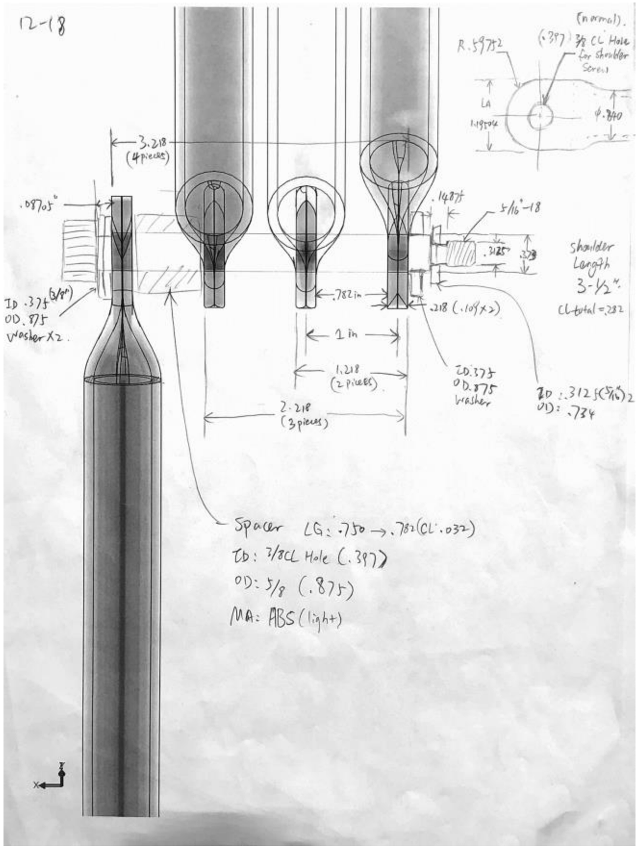


Figure 9 Manuscript for determining shaft connection

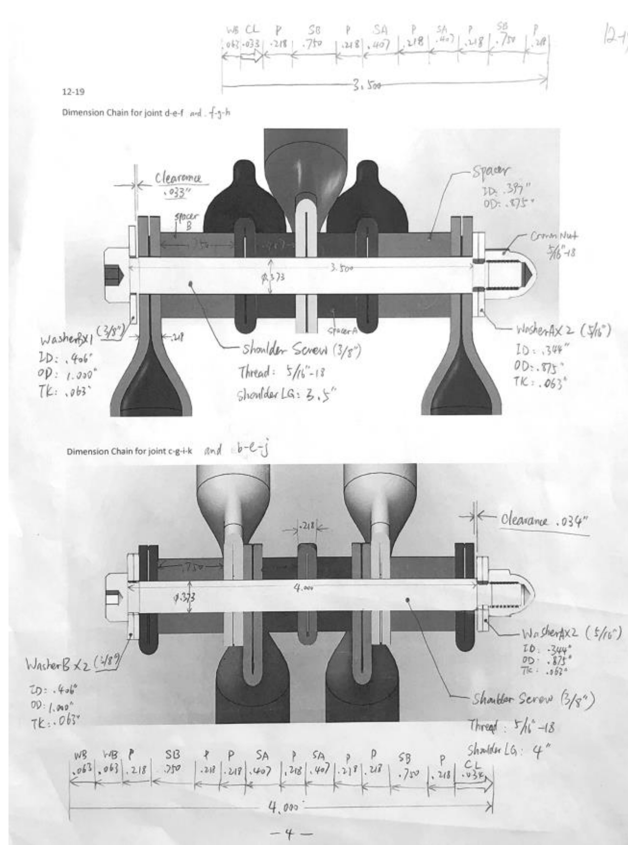


Figure 10 Manuscript for Dimension Chain calculation

Figure below shows a deprecated design prototype for Rotating Crank Subsystem.

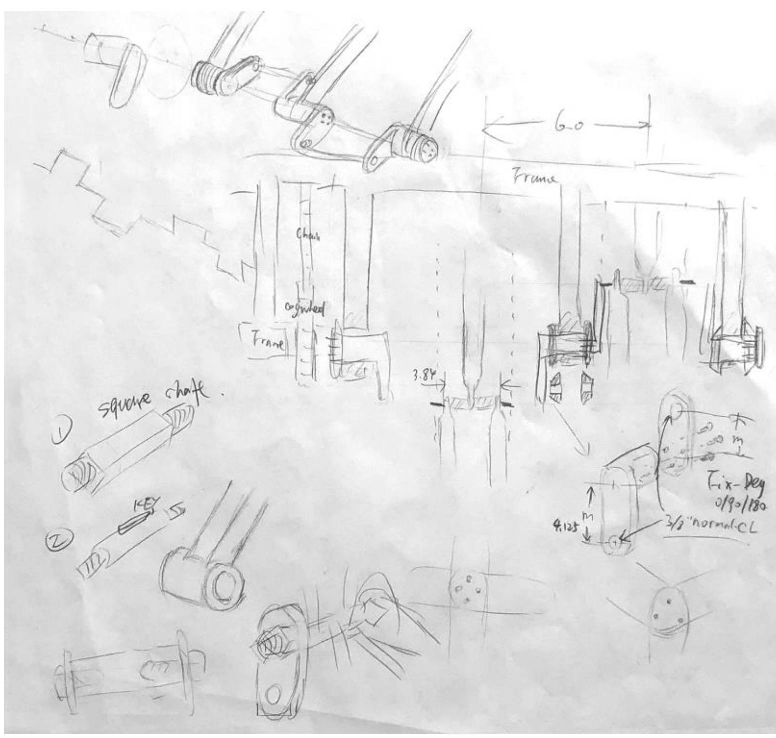


Figure 11 Manuscript for Rotating Crank prototype (Deprecated)

3D MODELING

Software Choice

In this project, I used SOLIDWORKS 2018 educational version as my working software. Parts, assemblies, drawings, rendered images and videos will be finished in SOLIDWORKS and SOLIDWORKS Visualize.

Design Table, **Equations**, **Toolbox**, **Welding**, **Structural Shape Features**, **Sprockets and Chains** are used in this project.

Leg Subsystem

To lighten the weight, I chose 6061 Alloy pipes as my initial material to manufacture. This material is cheap, light and fairly strong to support the weight of the whole product as well as an adult human.

Starting from choosing the proper size of the pipe on the market:

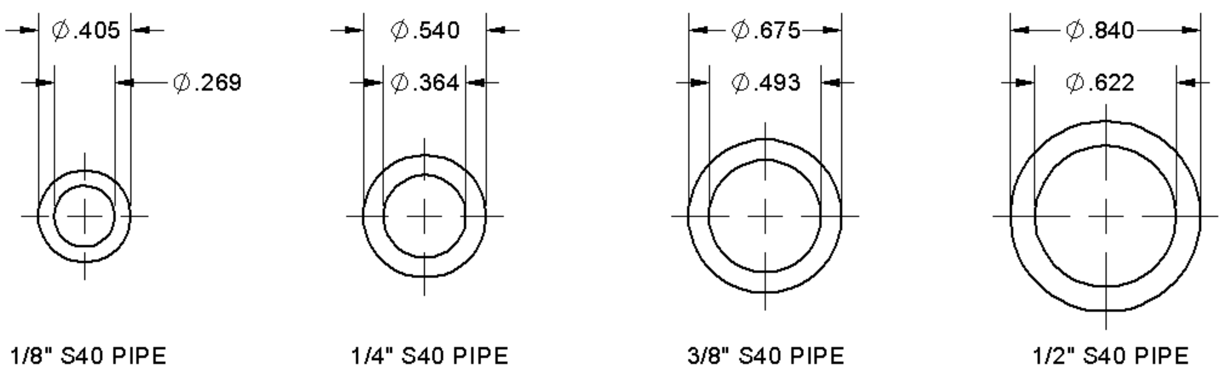


Figure 12 Some available 6061 alloy pipe size on the market

Considering the force and overall size of this project, I chose 1/2" S40 6061 Alloy Pipe.

Detail size: OD ∅.840", ID ∅.522", Thickness.109", Length available on market: 1', 3', 6'

The manufacturing processes of the leg part will be 3 steps:

- Squeeze the pipe's both ends
- Cut the flattened area with a round feature on each side
- Drill a clearance hole for the connecting shaft on each side

The manufacturing steps is shown on Figure 13 in the next page. The sequence of these procedures is also applied in 3D-modeling in the software.

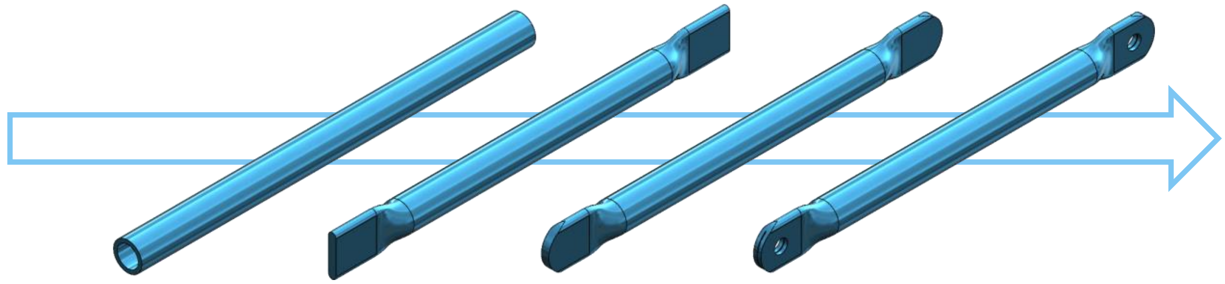


Figure 13 Manufacturing steps for leg pipes

To reuse this file for all leg pipes, **Design Table** and **Equations** are used in SOLIDWORKS.

Design Table for: OP40001 Pipe-Leg		
	CD@FD	$COLOR
Scale	0.2750	15592165
a	10.4500	15577165
b	11.4125	15562165
c	10.8075	15547165
d	11.0275	15532165
e	15.3450	15517165
f	10.8350	15502165
g	10.0925	15487165
h	18.0675	15472165
i	13.4750	15457165
j	13.7500	15442165
k	17.0225	15427165
l	2.1450	15412165
m	4.1250	15397165

Table 2 Design table for leg pipes

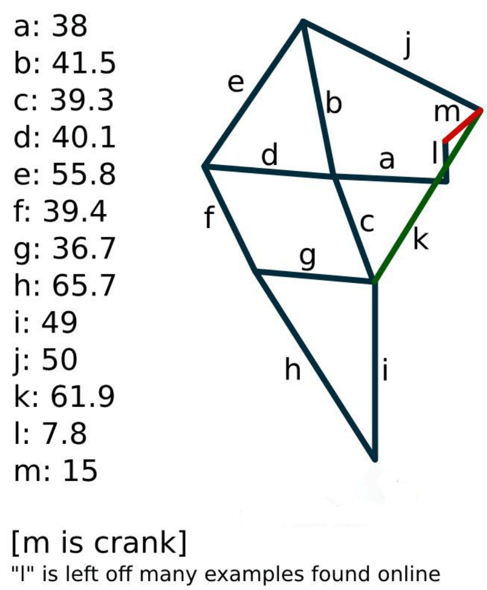


Figure 14 Referred pipe ratio with configuration names

Name	Value / Equation	Evaluates to	Comments
⊟ Global Variables			
"OL"	= "FL" + "FD"	11.645in	Overall Length (available on Mc 1 3 6)
"EL"	= 2in	2in	Edge Length to be squeezed
"LO"	= .8in	0.8in	Loft Offset to pipe edge
"OD"	= .84in	0.84in	Outside Diameter of 1/2 pipe
"ID"	= .622	0.622	Inside Diameter of 1/2 pipe
"TK"	= ("OD" - "ID") / 2	0.109	Thickness of 1/2 pipe
"FL"	= "CD@FD"	10.450in	Functional Hole-to-Hole Length
"LS"	= Pi * (("OD" ^ 2 - "ID" ^ 2) / 4 - "TK" ^ 2) / (2 * "TK")	0.977035in	cross section Length of after Squeeze
Thickness	= 1.000	1.000in	
Add global variable			
⊟ Features			
"FD"	= "LS" + "TK" * 2	1.19504	overall Diameter of flat Fillet edge
Add feature suppression			
⊟ Equations			
"PLS@Main-Body"	= IIF ("CD@FD" + "FD" - 2 * "EL" > 0 , "CD@FD" + "FD" - 2 * "EL" , 0.00001in)	7.645in	Pipe Length of Straight part after squeeze
"LO@Plane1"	= "LO"	0.800in	
"OD@Sketch1"	= "OD"	0.840in	
"ID@Sketch1"	= "ID"	0.622in	
"TK@Sketch1"	= "TK"	0.109in	
"RS@Sketch3"	= "TK"	0.109in	
"LS@Sketch3"	= "LS"	0.977in	
"FL@Boss-Extrude2"	= "EL" - "LO"	1.200in	Flat area Length
"D1@Cut-Extrude1"	= "OD"	0.840in	
"D1@Shell4"	= "TK" - .01in	0.099in	
Add equation			

Table 3 Equations for leg pipes

Then I should consider how to connect those pipes. I had two plans to follow:

- Plan1: Flange Bolt + Spacer + Washer + Crown Nuts
- Plan2: Step Shaft + Retaining Rings -> Hard to assembly for those retaining rings

My final choice: Shoulder Screw + Spacers + Washers + Crown Nuts

When assembling pipes and spacers, I found that one single pipe is not stable for leg components, it can result in horizontal shaking that may cause vibration and deformation.

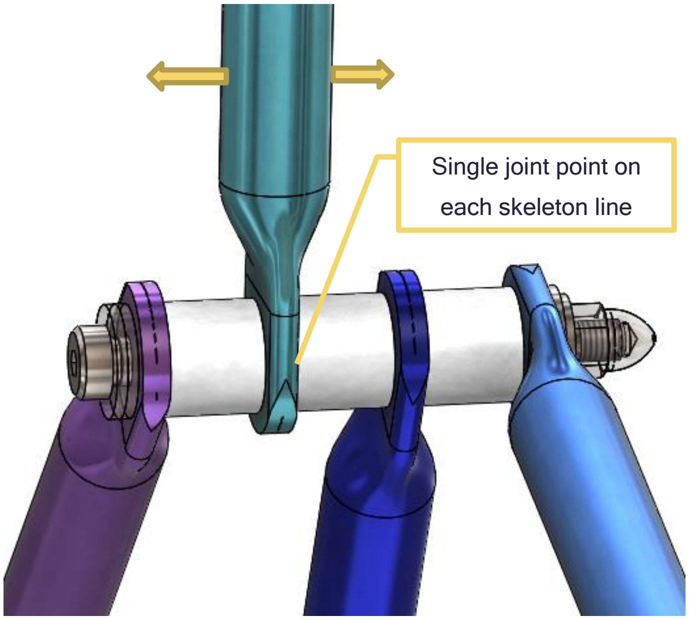


Figure 15 Leg joint using single pipe

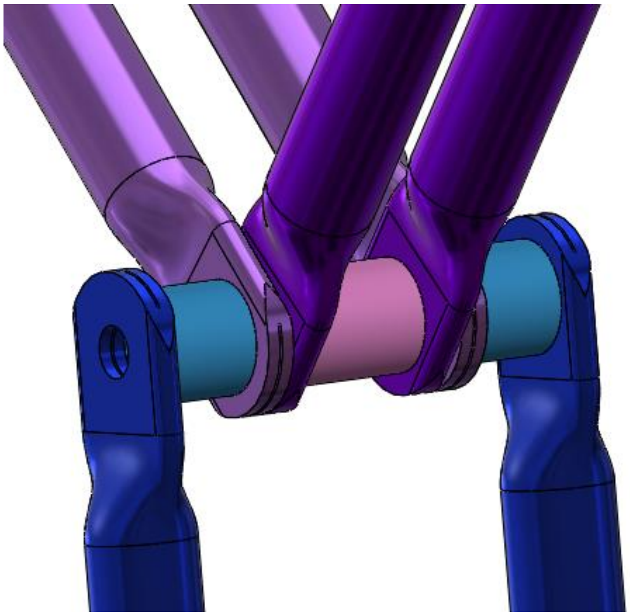


Figure 16 Leg joint using double pipes

Figure 17 Final sub-assembly of leg subsystem

Rotating Crank Subsystem

Rotating crank subsystem is the key connecting system which transfer the rotating force from chain system to leg subsystem so that the movable pipes on legs can rotate.
Rotating crank subsystem also works as a frame-based supporting system which hold the two key-axis on leg subsystem in position. It is also attached to the main vehicle body frame.

At first, I designed a Fixer-Deg with configurations (0/90/180/270 degrees to change each leg's orientation), using 4 tiny socket head cap screws to fix arm-angle from rotating. The original design is shown as below:

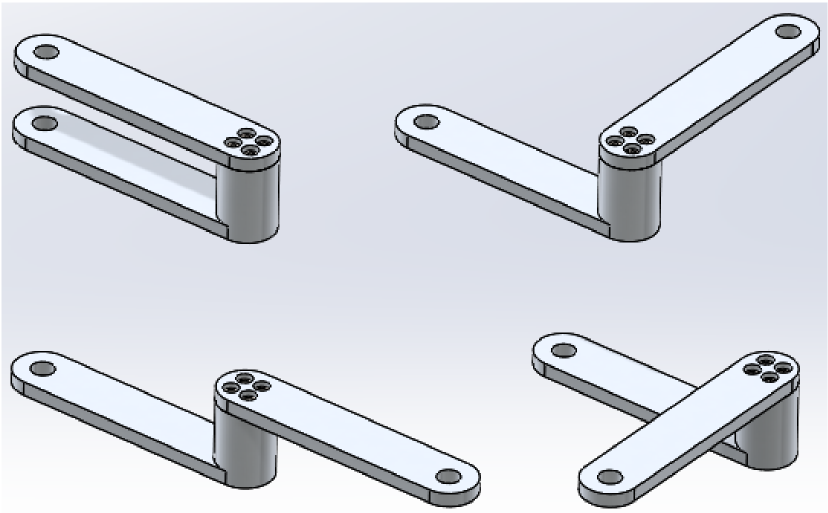


Figure 18 Original 4-screws fixer (Deprecated)

Then I found that Fixer-Deg's Shaft part is too thick, I should change them to separated square shaft parts with non-circular shaped shaft. A square shaft fixer is finally applied.

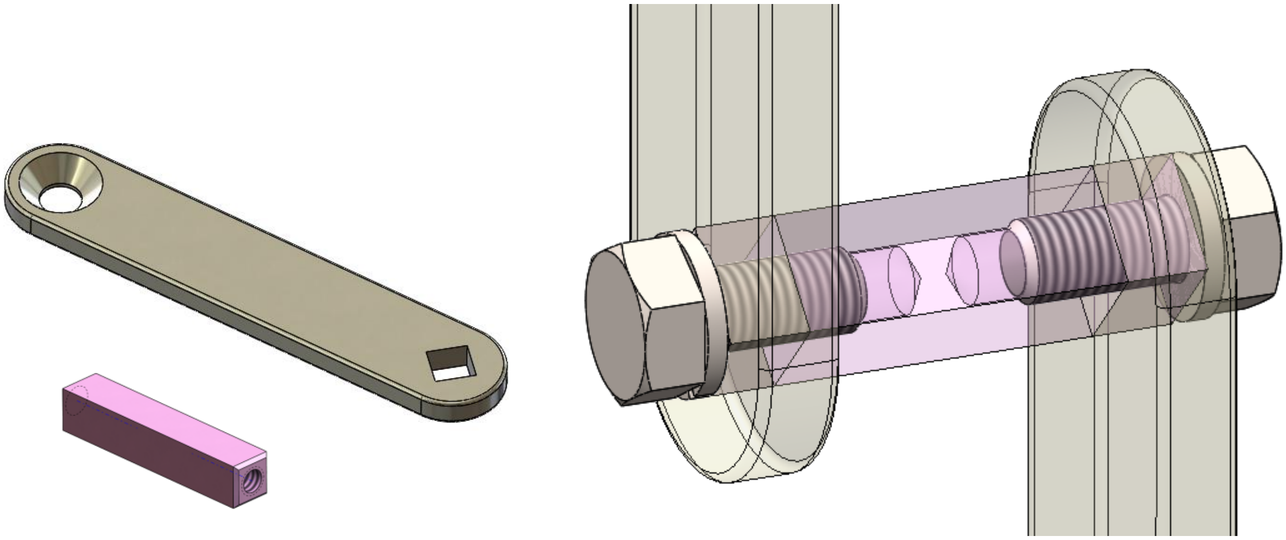


Figure 19 Improved square shaft fixer

The countersunk side of the fixer is used to connect the leg subsystem

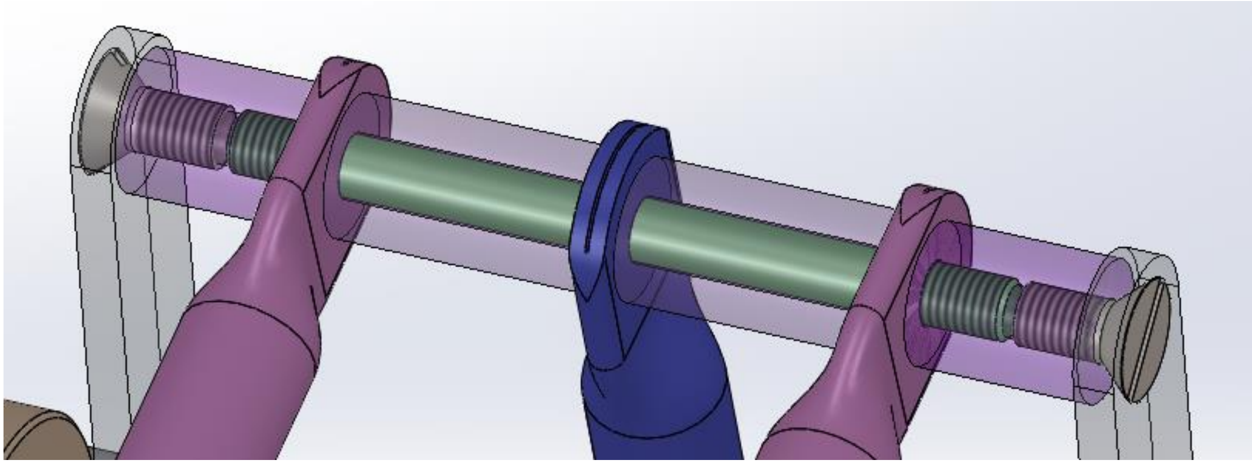


Figure 20 Connecting fixer in countersunk side

Now it's time to assemble multiple fixers in different orientations. At this time, I finally determined to use 4 legs on each side of the vehicle.

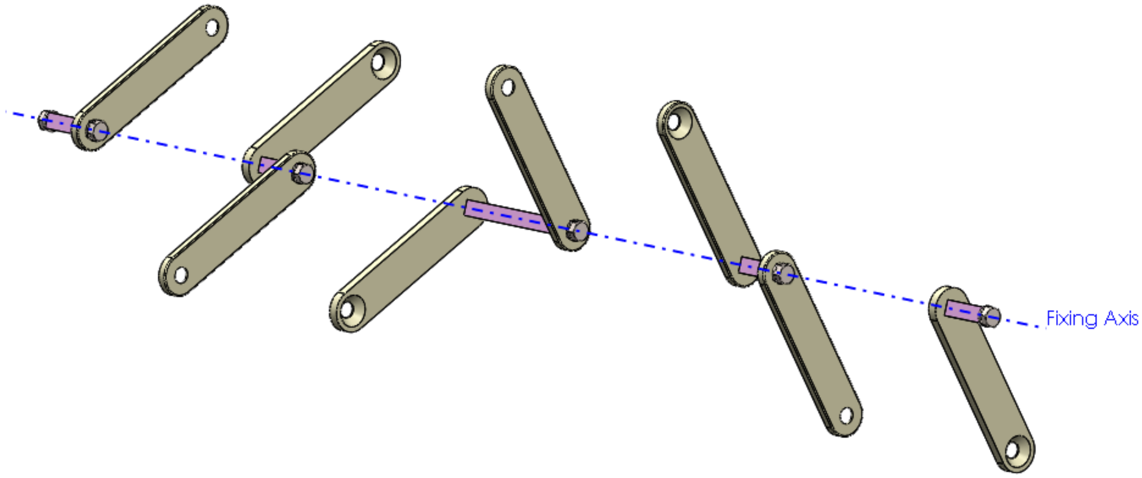


Figure 21 Multiple fixers and square shafts aligned

Using ball bearings is a good idea to reduce rotational friction and can have a better load support. Then weld structural pipes to outside of the bearing to fix them on rotating cranks' main structure.

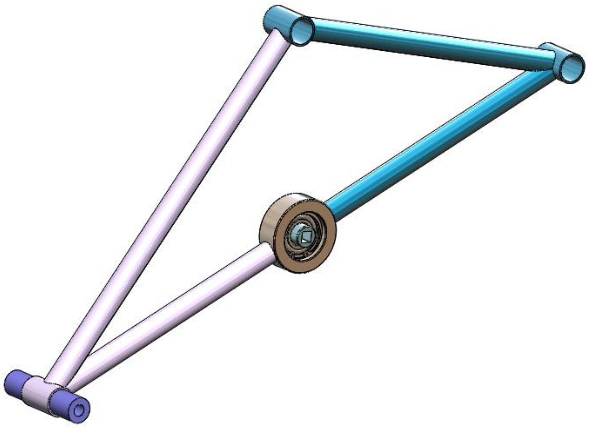


Figure 22 Bearing weldment

Noticed that the front rotating crank and the rear rotating crank are not the same size. Just need to made some tiny modifications on pipe lengths according to main body frame skeleton later.

The whole Rotating Crank Subsystem Front and Rear are shown as Figure 23 and Figure 24.

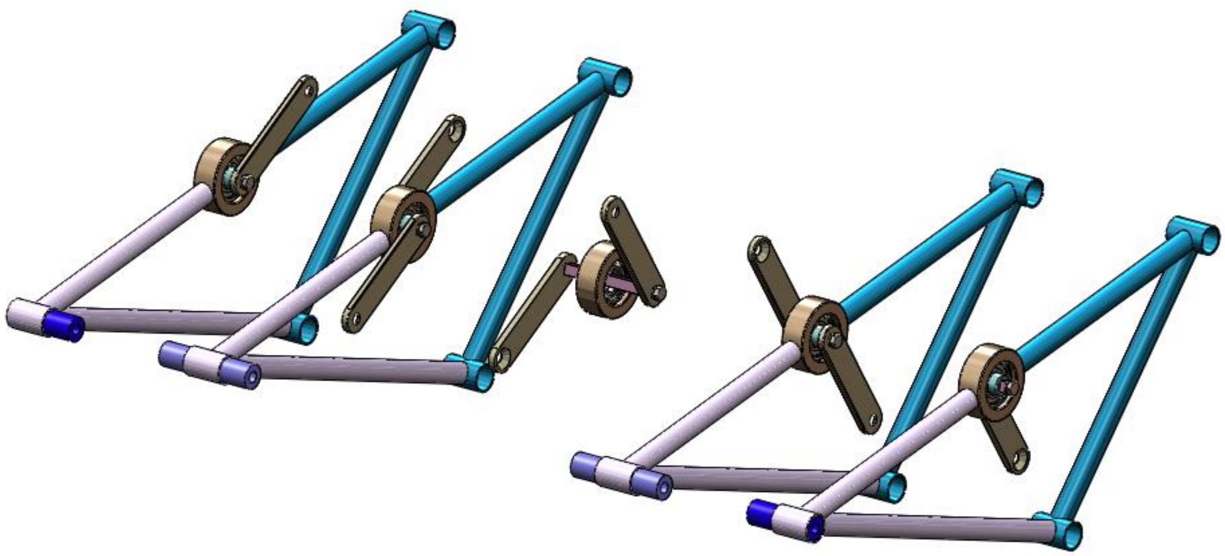


Figure 23 Rotating Crank Subsystem (Front)

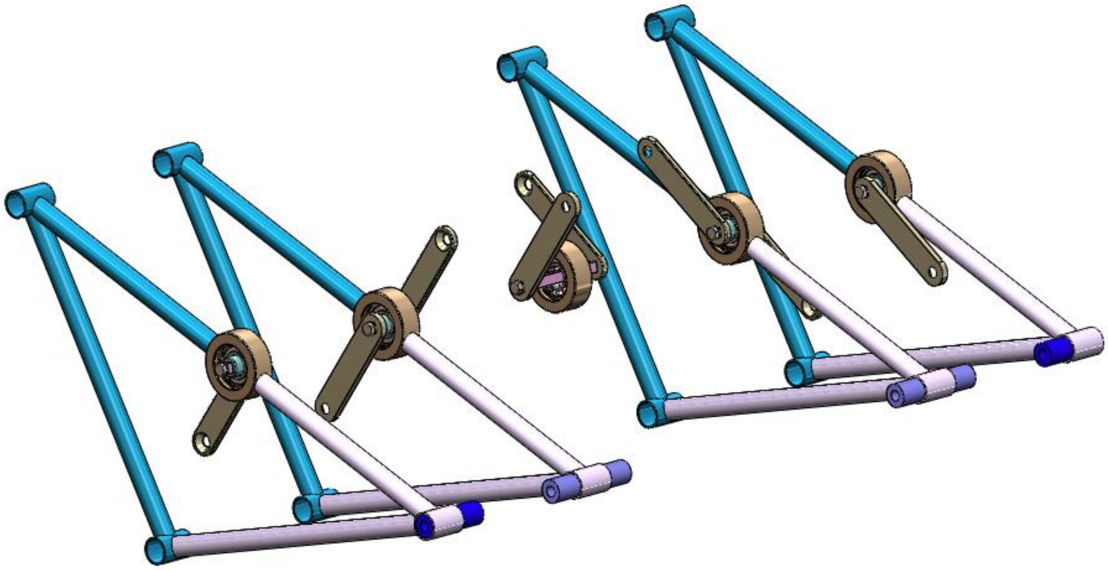


Figure 24 Rotating Crank Subsystem (Rear)

Body Frame

Body frame is mainly base on standard structural shapes (Pipes). Use 3D sketch lines as the skeleton of those pipes, then trim them to match their curved shape in order to weld them together as a rigid body.

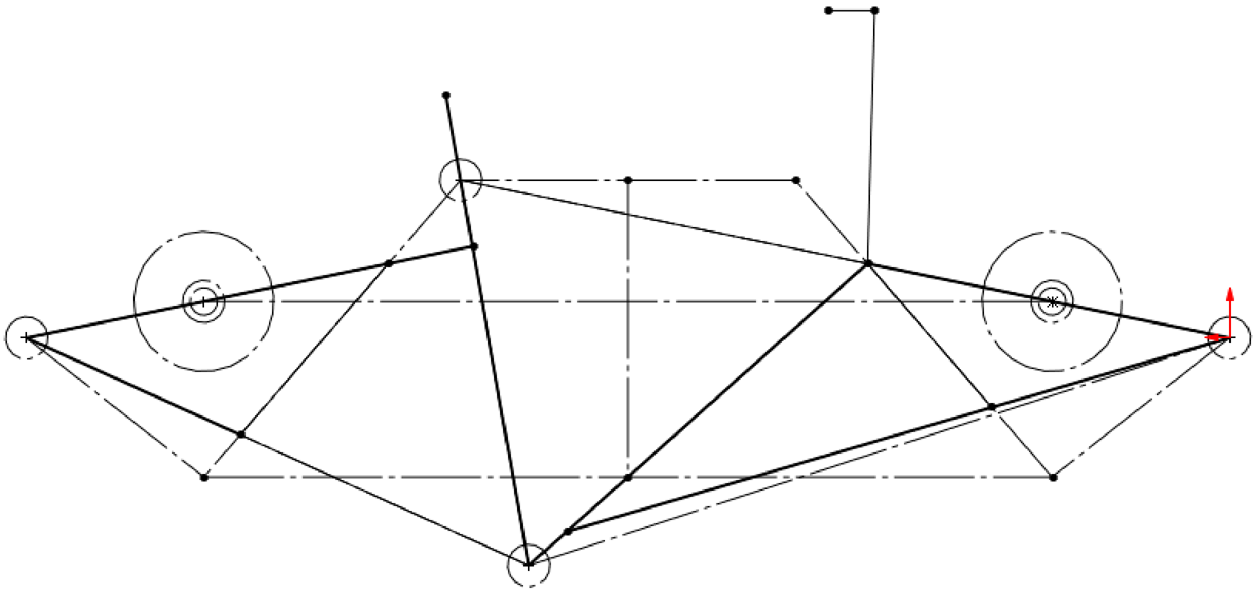


Figure 25 Skeleton for body frame

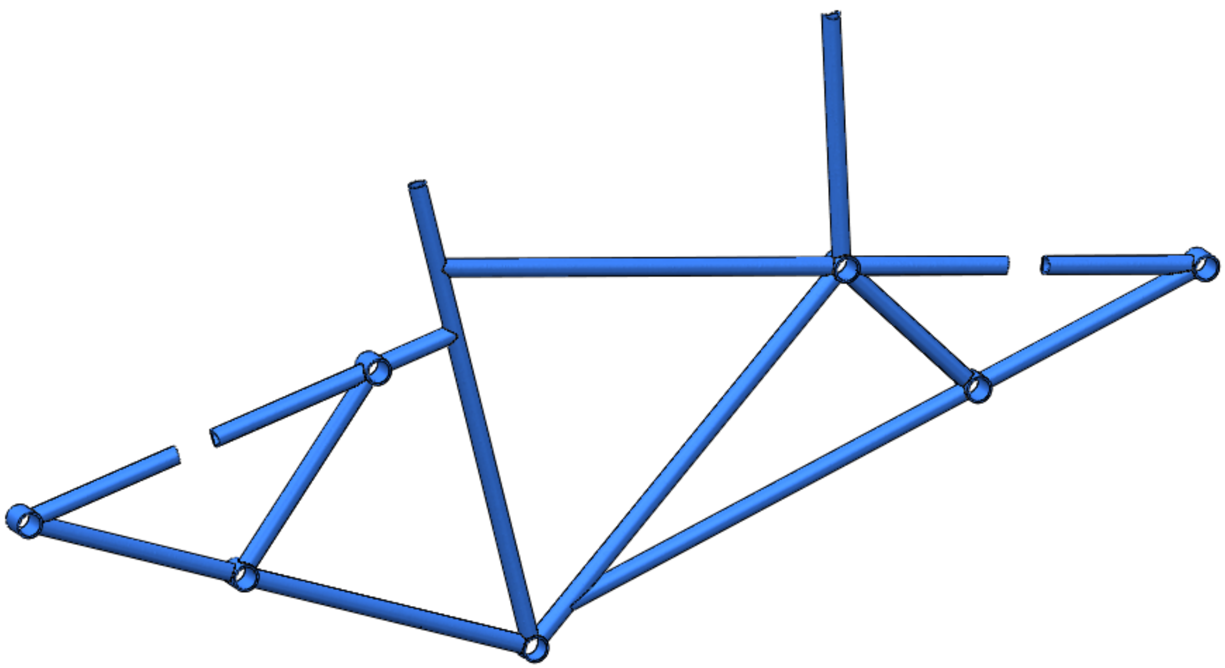


Figure 26 Body frame using standard structural pipes

Then add the seat, the handle subassembly (one of the handle holders is to be welded with the body frame) and the crank pedal subassembly.

In pedal subassembly, two big sprockets are used to drive the chain system which comes later.

The designation of the big sprockets will be listed in the following chapter: **Chain System**

Figure 27 Seat

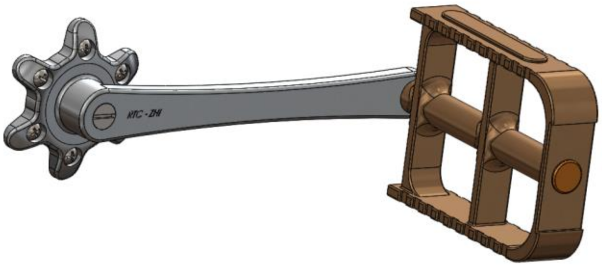


Figure 28 Crank Pedal Subassembly

Figure 29 Body frame with some subassemblies

Chain System

Chain system is the core transmission of the whole vehicle. It transmits the rotating movement from the big sprockets (which connecting to the pedal) to the two small sprockets installed on front and rear Rotating Crank Subsystem (which connecting to all legs).

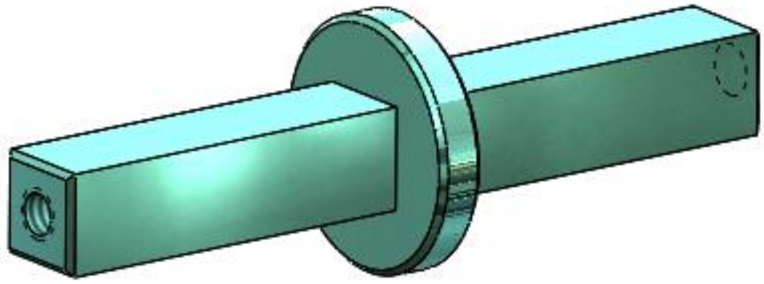


Figure 30 Square-shaped sprocket spacer shaft

Two big sprockets are assembled with two pedal subassemblies at the same time, using a sprocket spacer shaft (square-shaped, working as a step shaft)

The **Number of Teeth Ratio** between the Big sprocket and small sprocket determines how fast the leg rotates. Under the same angular velocity from human feet, the less teeth the small sprocket has, the faster the legs will rotate, the faster the whole vehicle will move forward.

Big Sprocket

Chain Number	40
Number of Teeth	45
Outer Diameter	∅7.450

Small Sprocket

Chain Number	40
Number of Teeth	10
Outer Diameter	∅1.893

Table 4 Designation of big and small sprockets

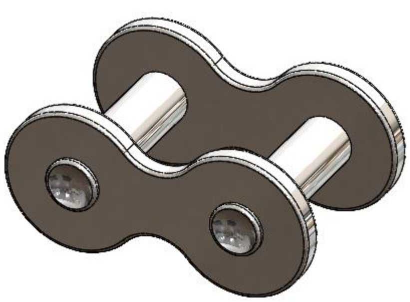


Figure 31 Inner Chain

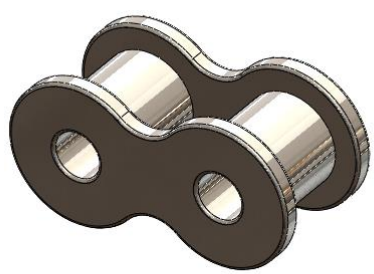


Figure 32 Outer Chain

The partial view of the Pedal – Sprocket – Chain system is shown as below:

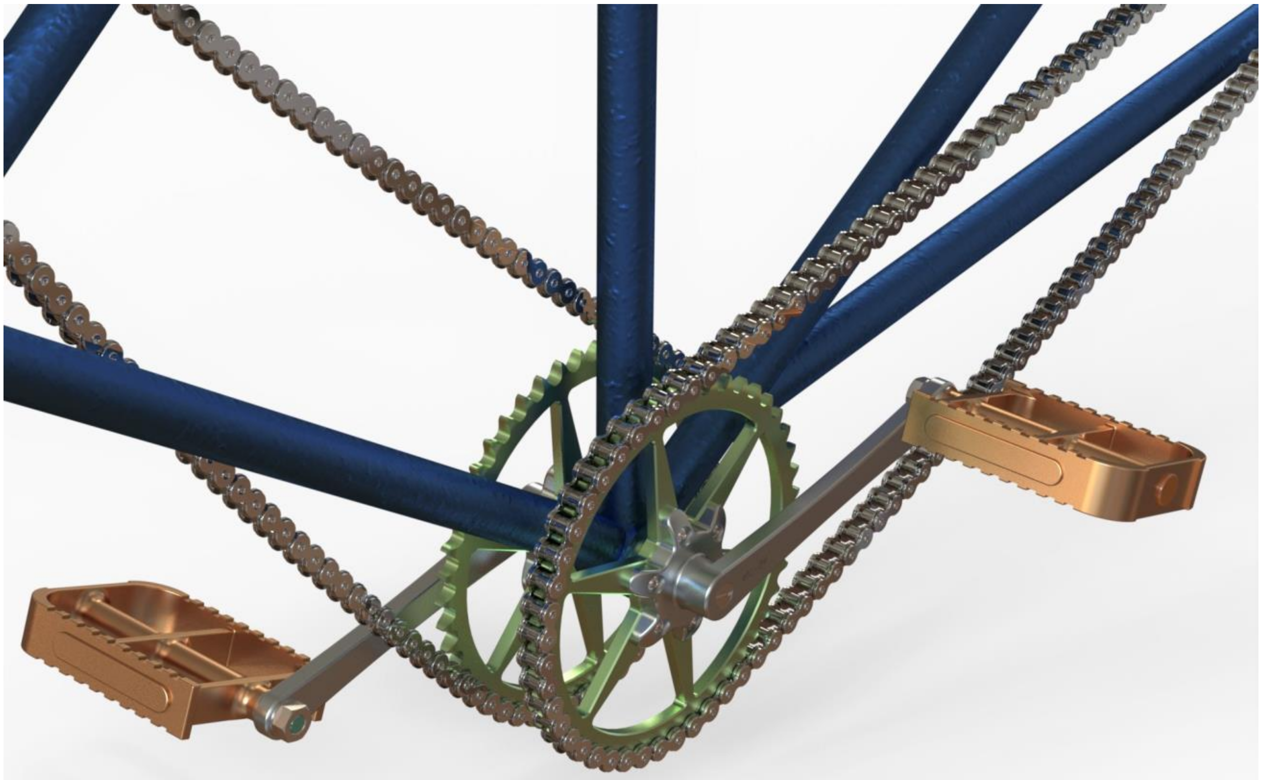


Figure 33 Big sprocket and chains (Partial View)

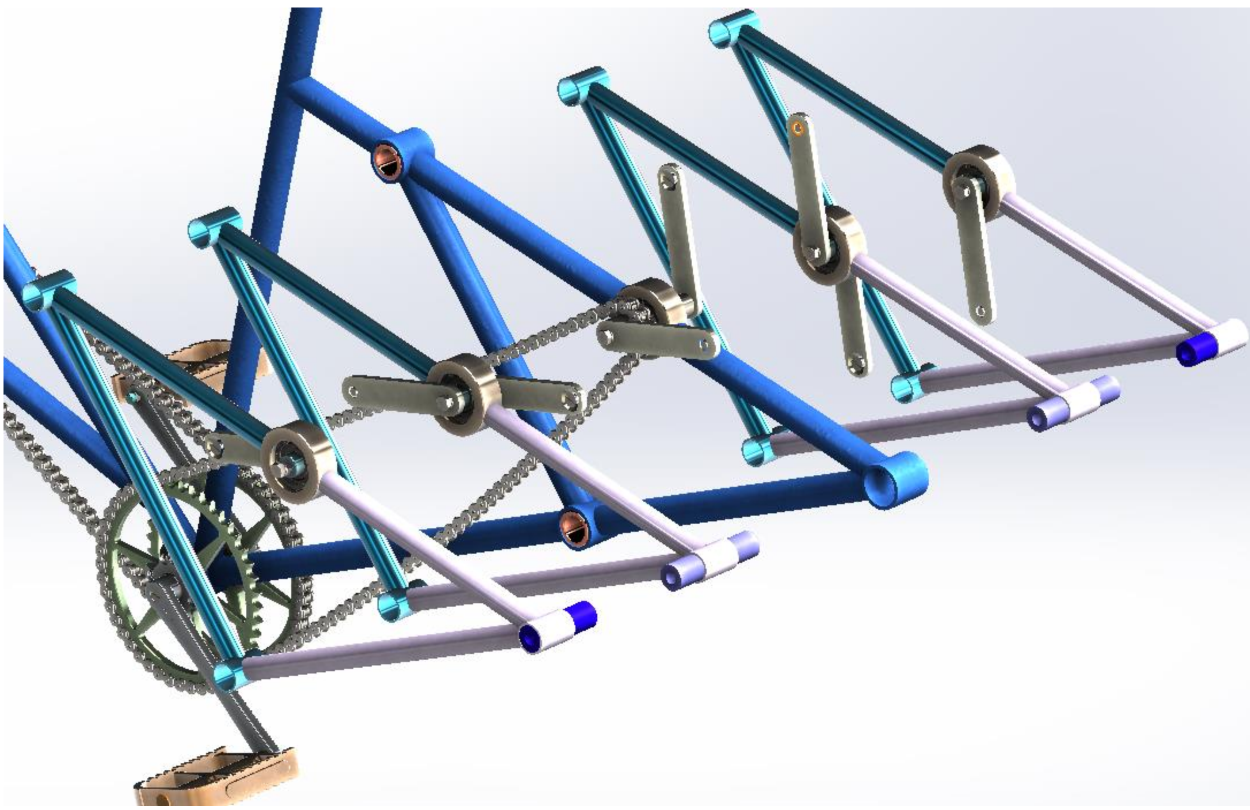


Figure 34 Small Sprocket and chains (Partial View)

Mannequin

Mannequin is not a part of the vehicle.
The usage of the mannequin assembly is to refer to a real-sized human body so that the overall size of the walking vehicle can match a normal person, as well as all detailed dimensions of seat, pedal subassembly and handle assembly are reasonably scaled.
To avoid time consuming, download standard parts is a good choice. The only modification to the mannequin model, is to carve some logo texts.

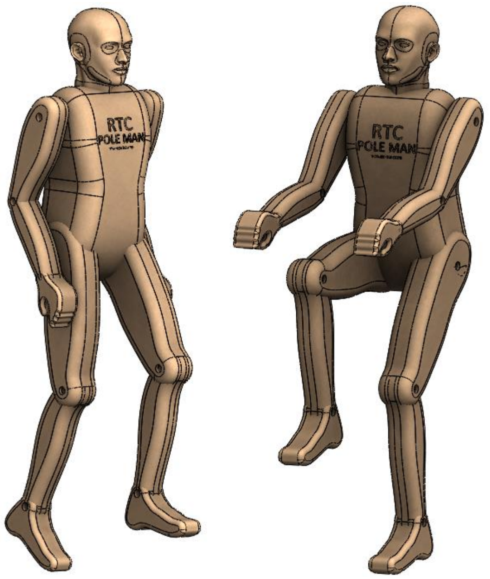


Figure 35 Mannequin model

Main Assembly

Now it's time to build the main assembly, putting **Body Frame**, **Chain System**, **Rotating Crank Subsystem**, **Leg Subsystem** and the **Mannequin** together. Some fasteners and some long shafts are used in this process. The file system will be listed on the next page.

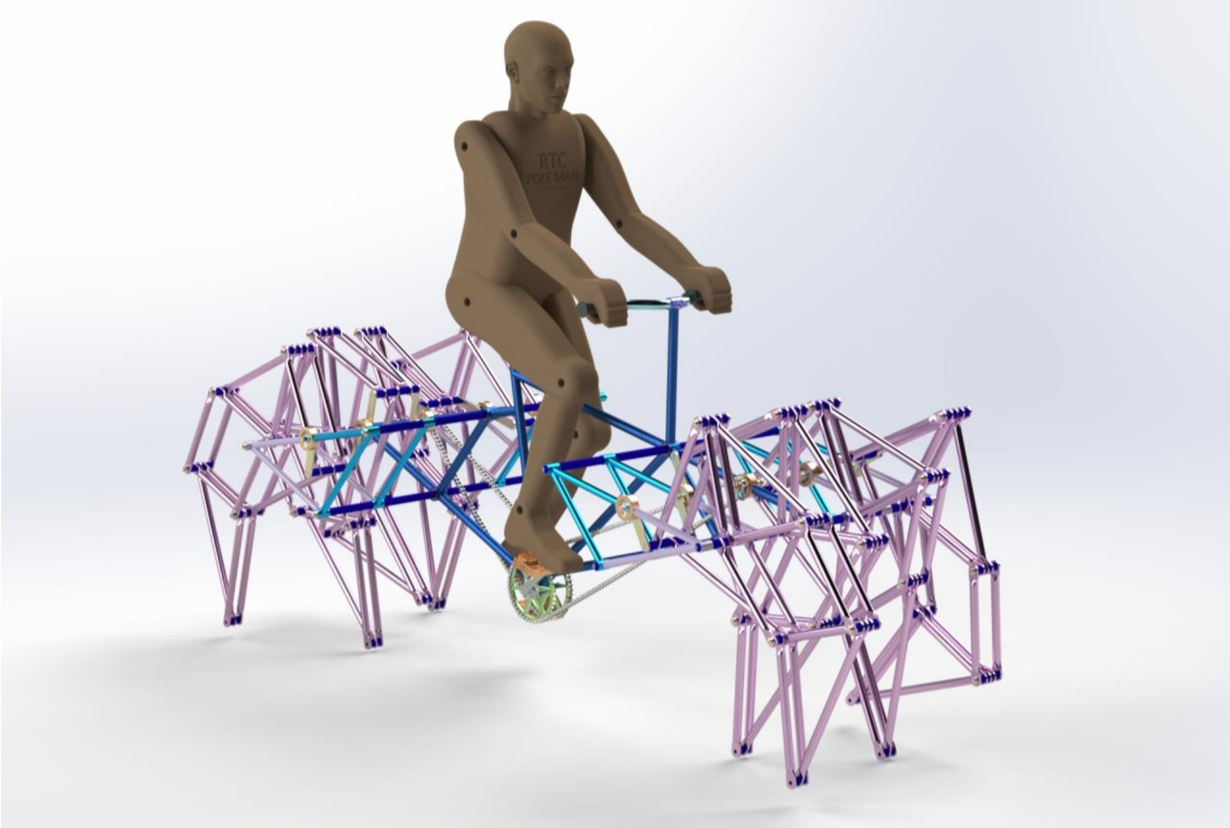


Figure 36 Main Assembly

The file system (partial) after main assembly is shown as below:

OP00000 Octopied.SLDASM

OP10000 Body Frame.sldasm
OP11000 Crank Pedal.sldasm
OP11000 Crank Pedal.SLDDRW
OP11001 Crank.SLDDRW
OP11002 Pedal-Shaft.SLDDRW
OP11003 Pedal.SLDDRW
OP10001 Main Structure.SLDPRT
OP10002 Seat.SLDPRT
OP11001 Crank.sldprt
OP11002 Pedal-Shaft.sldprt
OP11003 Pedal.SLDPRT

OP12001 Sprocket-Big-45.SLDDRW
OP12002 Sprocket-Small-10.SLDDRW
OP12003 Sprocket-Spacer.SLDDRW
OP12001 Sprocket-Big-45.SLDPRT
OP12002 Sprocket-Small-10.sldprt
OP12003 Sprocket-Spacer.SLDPRT
OP12004 Needle Roller Bearing.SLDPRT
OP12005 Inner Chain.SLDPRT
OP12006 Outer Chain.SLDPRT

OP20000 Rotating Crank-FRONT.SLDASM
OP21000 Bearing-Welding-FRONT.SLDASM
OP21100 SubA-Bearing.sldasm
OP21200 SubB-Bearing.sldasm
OP30000 Rotating Crank-REAR.SLDASM
OP31000 Bearing-Welding-REAR.SLDASM
OP20001 Sq-Shaft.SLDDRW
OP20002 Fixer-SK.SLDDRW
OP21000 Bearing-Welding-FRONT.SLDDRW
OP21001 Leg-Frame-FRONT.SLDDRW
OP21100 SubA-Bearing.SLDDRW
OP21101 Housing-B.SLDDRW
OP21102 Bushing.SLDDRW
OP20001 Sq-Shaft.sldprt
OP20002 Fixer-SK.sldprt
OP20003 Leg-sim.sldprt
OP20004 Chain Sprocket.sldprt
OP21001 Leg-Frame-FRONT.sldprt
OP21101 Housing-B.SLDPRT
OP21102 Bushing.SLDPRT
OP31001 Leg-Frame-REAR.sldprt

Pipe-Leg-Table.xlsx
Spacer-Ro-Table.xlsx
OP40000 Leg-Assembly-V0.SLDASM
OP40000 Leg-Assembly-V1.SLDASM
OP40000 Leg-Assembly-V2.SLDASM
OP41000 Leg-TriTop.SLDASM
OP42000 Leg-TriBtm.SLDASM
OP43000 Leg-c.SLDASM
OP44000 Leg-f.SLDASM
OP45000 Leg-j.SLDASM
OP40001 Pipe-Leg.SLDDRW
OP40002 Spacer-Ro.SLDDRW
OP40003 Middle-Shaft.SLDDRW
OP40001 Pipe-Leg.SLDPRT
OP40002 Spacer-Ro.sldprt
OP40003 Middle-Shaft.sldprt
OP40004 Spacer-Tri.sldprt
OP40005 Leg-Spacer.SLDPRT
OP40006 Long-Shaft.sldprt

OP60000 Human.sldasm
OP60001 Abdominal.SLDPRT
OP60002 Head.SLDPRT
OP60003 Arm.SLDPRT
OP60004 Forearm.SLDPRT
OP60005 Hand.SLDPRT
OP60006 Thigh.SLDPRT
OP60007 Leg.SLDPRT
OP60008 Foot.SLDPRT

Figure 37 File system (Partial)

TECHNICAL DRAWINGS

Part Drawing

Part drawing contains every detail feature of a part.

Some of the dimensions are very important functional dimensions of which the tolerances are critical to a mechanical assembly.

To determine the proper mates between different parts, the Dimension Chain technique is applied. (See MANUSCRIPT chapter, Figure 10 Manuscript for Dimension Chain calculation)

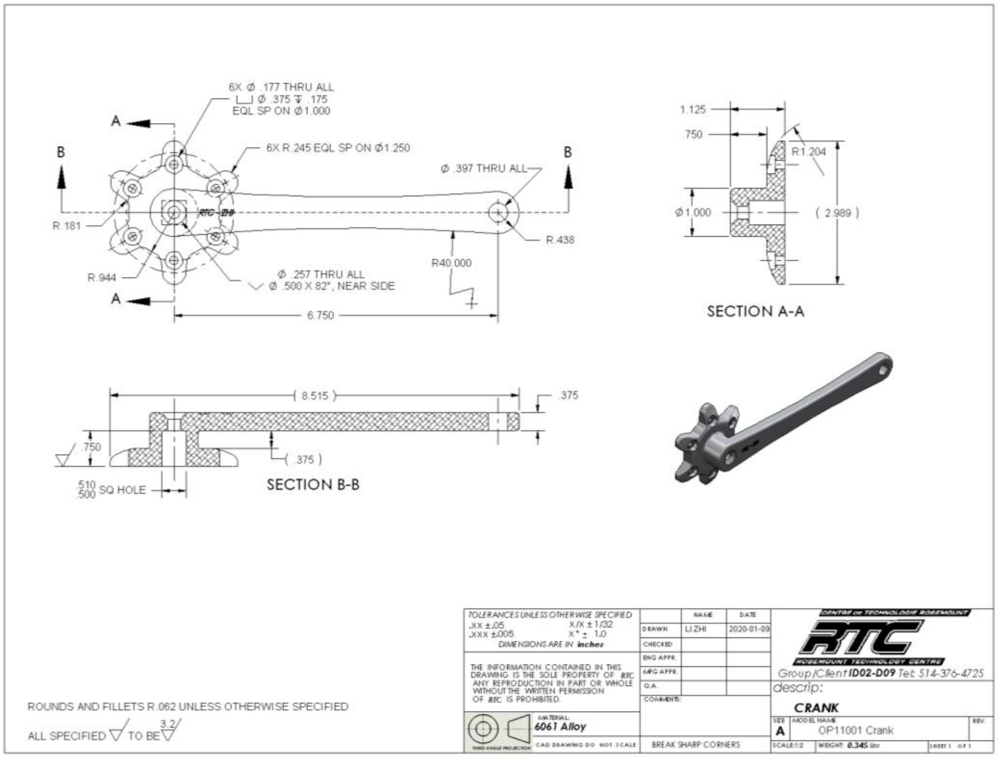


Figure 38 Part drawing example – part to be manufactured

In this project, some weldments are also used to permanently connect those standard structural shapes (pipes) together. In this case, a welding table will be added to the part drawing. See Figure 39 Part drawing example - weldment in next page.

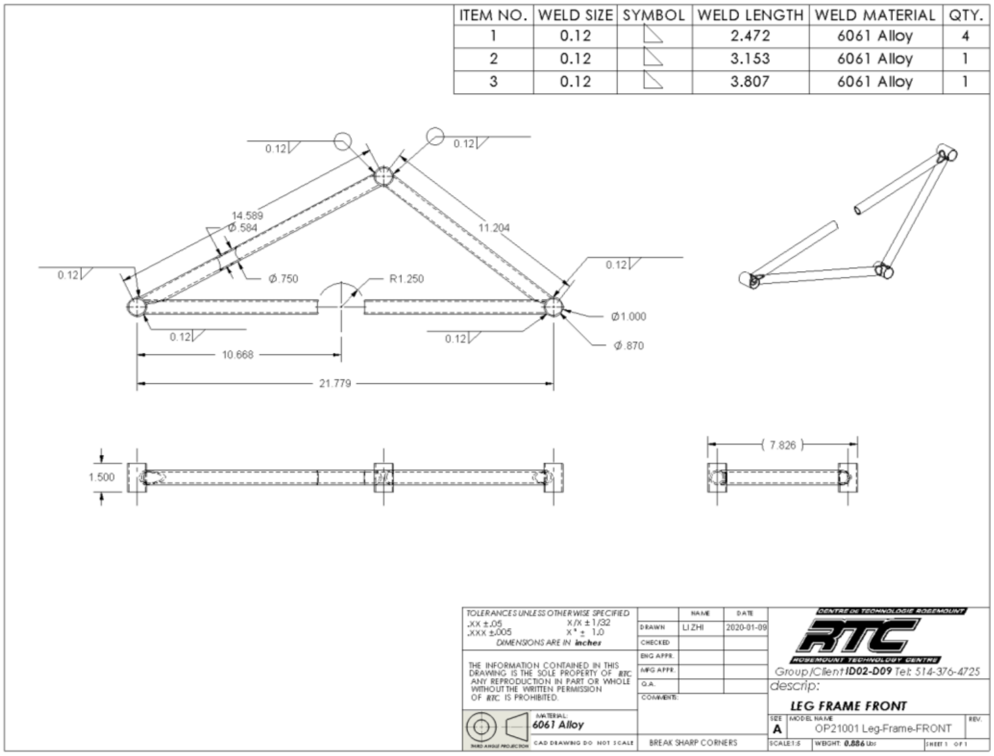


Figure 39 Part drawing example - weldment

Certain parts have their proper designation table, for example, for a sprocket, we need to signify its chain number, number of teeth, outer diameter in a table.

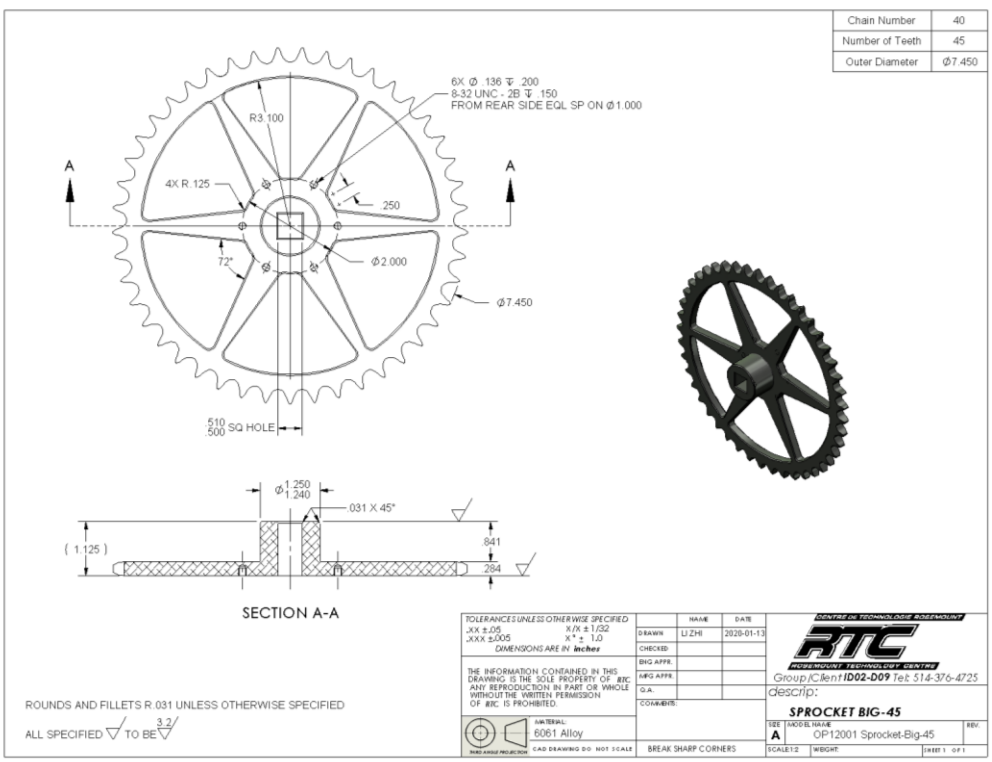


Figure 40 Part drawing example – transmission component

Assembly Drawing (Exploded View)

Unlike part drawing, assembly drawing demonstrates multiple parts with their position relationships.

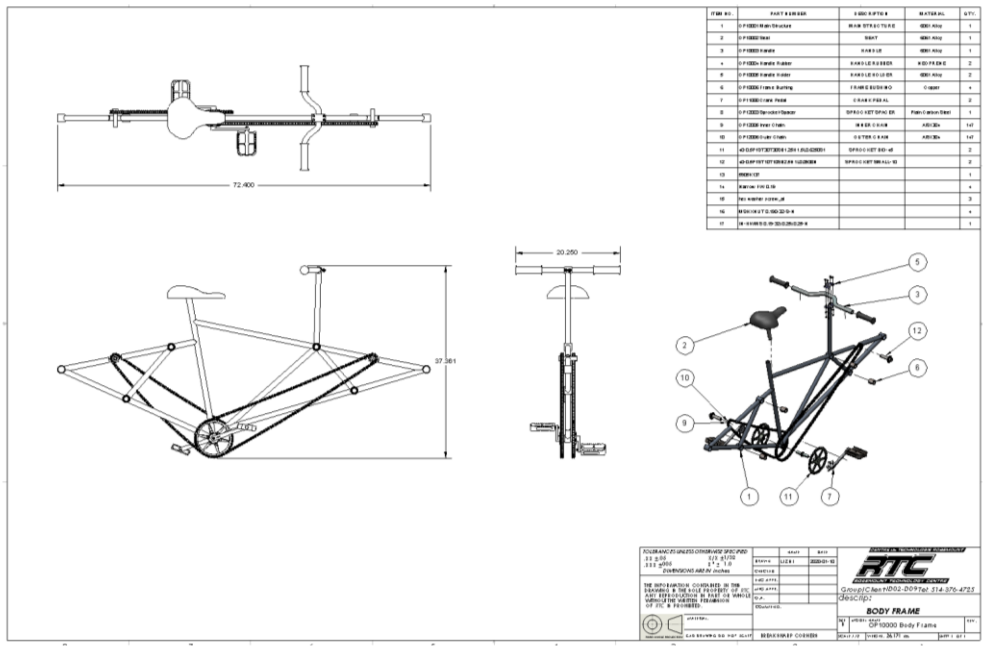


Figure 41 Assembly drawing example - body frame

With exploded view, we can have a better understanding of the assembly/subassembly's inner structure and how the components are assembled together.

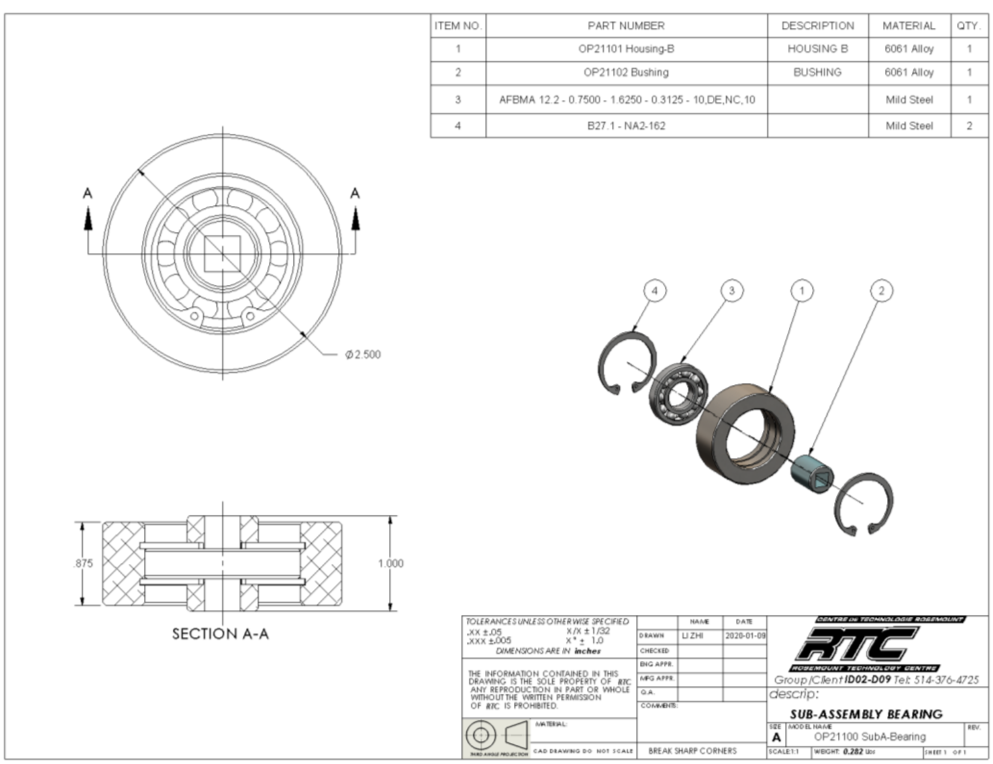


Figure 42 Assembly drawing example - bearing subassembly

RENDERING

Rendering Images

Rendering is the final procedure to demonstrate what a project is, how it looks like, and how it runs its inner mechanical systems.

For general use, the built-in render tool is strong enough to output images with good quality.

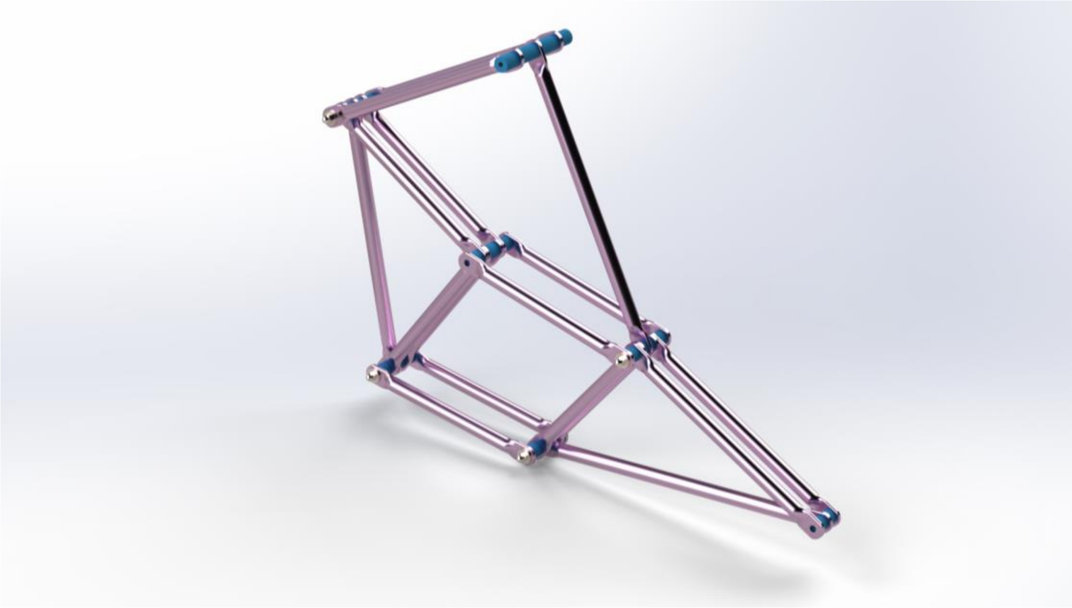


Figure 43 Rendered image of Leg-Subassembly

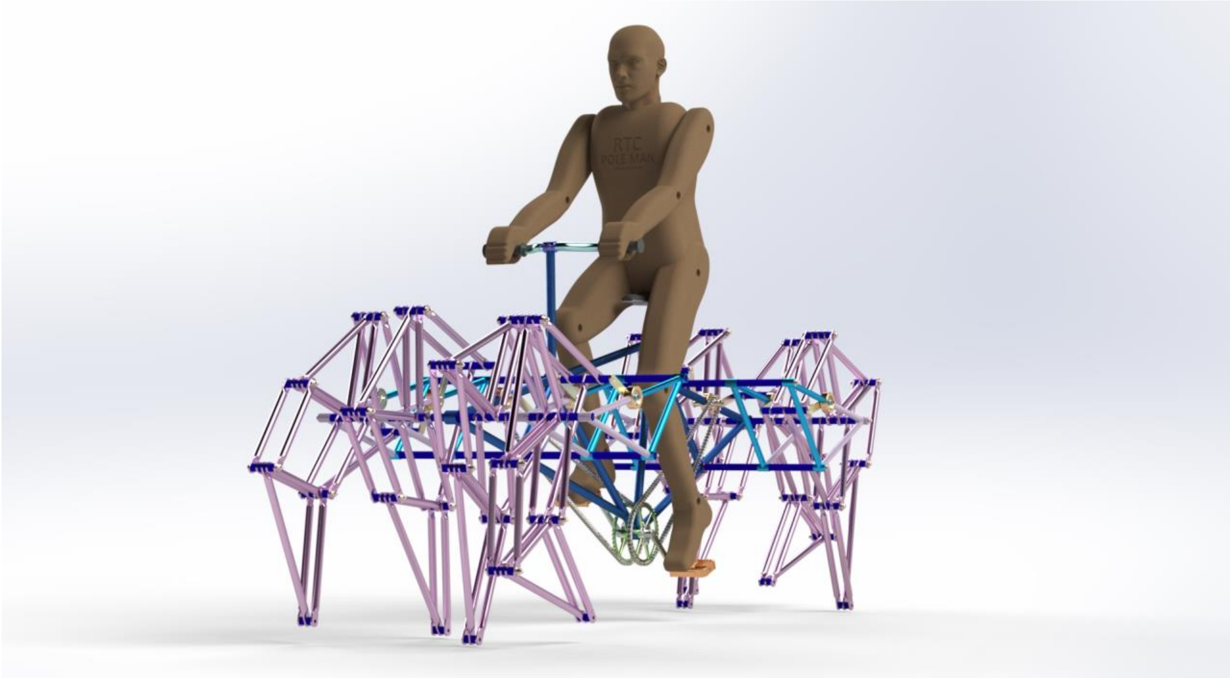


Figure 44 Rendered image of whole project with Mannequin

Rendering Animations

However, the built-in render tool is much less capable of rendering animations, no matter if it is an **Animation Study** or a **Turntable Demonstration**.

In this project, multiple 3D-Render softwares are applied in order to render out specific high-quality animations.

SOLIDWORKS	SOLIDWORKS VISUALIZE	KeyShot
• Direct Output in Study	• HQ Turntable Animation	• Advanced Animation
• Inspection Use	• GPU Accelaration	• Advanced Camera Movement
• Fast Draft Video	• CUDA Supported	• DOF Features
		• Scene Library Built-in
		• Cluster Rendering Supported

Table 5 3D-Render softwares

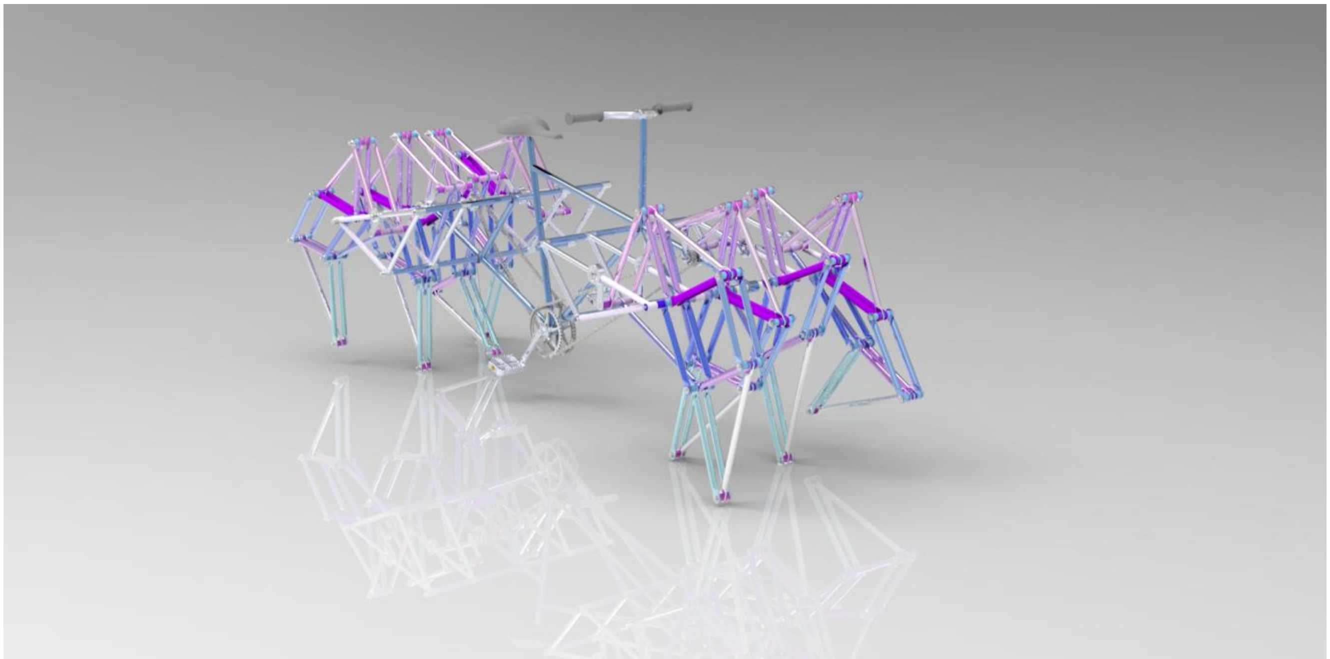


Figure 45 Screenshot of rendered walking animation (by KeyShot)

Rendering these videos is really time-consuming. Some of them have taken more than 4 hours for just 15 seconds video.

A good NVIDIA graphic card with CUDA support will highly reduce the rendering duration.

CONCLUSION

General Statement

This report introduced a wheel-less human-powered design for a bicycle-liked vehicle.
The Octapied vehicle would be more expensive and heavier than normal bicycles, but it is useful in some certain circumstances where no cars nor bikes nor helicopters can reach.
In some extreme cases in woodlands, Octapied is the best solution to be the first-aid vehicle.
Information about the geometric theoretical research, mechanical transmission system, materials and manufacturing process are presented in this report.
Some technical drawings and rendered images are demonstrated to help understanding.

How was this module useful to a draftsperson

A newbie draftsperson can never know how much knowledge he/she don't know unless he/she is fully in charge of a whole new design project by his/her own.
During the whole project, the best experience I've got is that, when encounter unknown technology or knowledge, how to collect useful information under resources I have, how to research the problem to get multiple solutions, how to determine which choice is the most suitable for my project.

I have practiced these core knowledges come from all modules in Industrial Drafting:
- A mixed Top-Down Design and Bottom-up Design
- Material and manufacturing process
- Determine functional dimensions with dimension chains, mechanical tolerances and fittings
- Gear/Sprocket transmission relationships
- Standard structural shapes and welding
- The usage of design table, equations and toolbox
- The management of file system
- How to research and find a solution to a technical problem
- How to complete a full technical report of a real project

I've also learned some new stuffs, some new software techniques that I've never been taught:
- How to make chain pattern with path using assembly features in SolidWorks
- How to mate the sprockets and chains with BeltMates and RackPinionMates
- How to make use of SolidWorks Visualize and KeyShot for rendering images/animations

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[5] Strandbeest Explains https://www.strandbeest.com/

[6] Jansen - Klann Linkage Comparison http://web.archive.org/web/20150305110753/http://www.mechanicalspider.com/comparison.html

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