Designing Extension Arms

A brief overview of important mechanical design elements for extension arms in robotics

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Overview

- Defining the purpose of an extension arm
- Stiffness/rigidity vs. shape
- Controlling oscillation with damping
- Types of joints and controlling accuracy
- Examples/case studies

Note: This is a very brief intro to these topics highlighting some common misconceptions and aimed at giving some ideas and search terms to go further on your own.

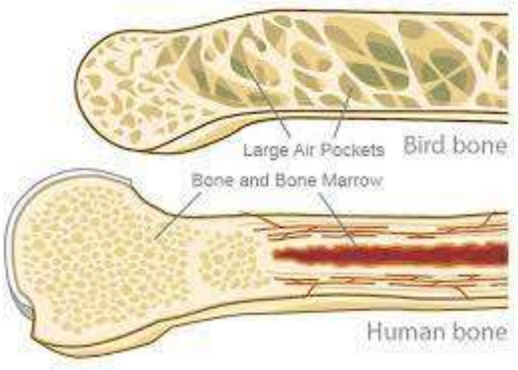
Define the Purpose of Extension Arm

- Does it need to be fast?
- How accurate does it need to be?
- How large or small does it need to be?
- Does it need to have a long reach?
- How many cycles does it need to last?

Try to answer these types of questions in the most quantitative way possible, but do not over-constrain yourself by ignoring other options.

Stiffness/Rigidity vs. Shape

- Shape is #1 for determining stiffness
- For the same shape, material choice then dictates stiffness
- Controlling accuracy, speed, and oscillation are heavily dependent on stiffness/rigidity.
- The optimal shape for real life loading is never a simple shaped tube, cylinder or bar. (exception for pure torsion being a hollow tube)
- Tradeoffs happen for ease of manufacture.



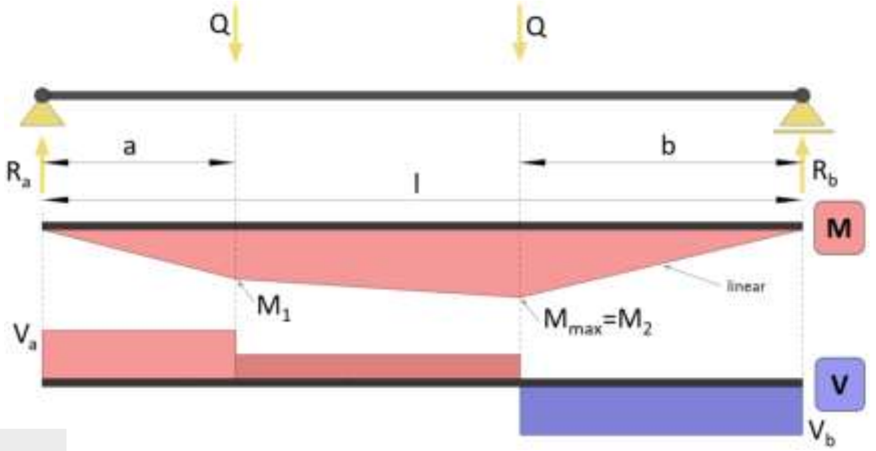
For more information and ideas on this topic consider looking up:

- Bending moment of inertia
- Second Moment of Area
- Bending and Shear in Beams

Stiffness/Rigidity vs. Shape (Contd.)

Simple loads still are optimal for weight with complex shapes, but for a good balance of performance to effort there are a few simple rules:

- If bending is the main force, make the shape like an I beam for one direction or square tube or hollow cylinder for multi Directions
- Use 3D printing or other reinforcement at connections or point loads.



Area	Shape	Second Moment of Area	Percent compared to solid Triangle
1	hollow square t=S/10 (36%solid)	0.380	394.5
1	hollow circle t=D/10 (36%solid)	0.362	376.6
1	solid equilateral triangle	0.096	100.0
1	solid square 45 degrees	0.083	86.6
1	solid square	0.083	86.6
1	solid circle	0.080	82.7

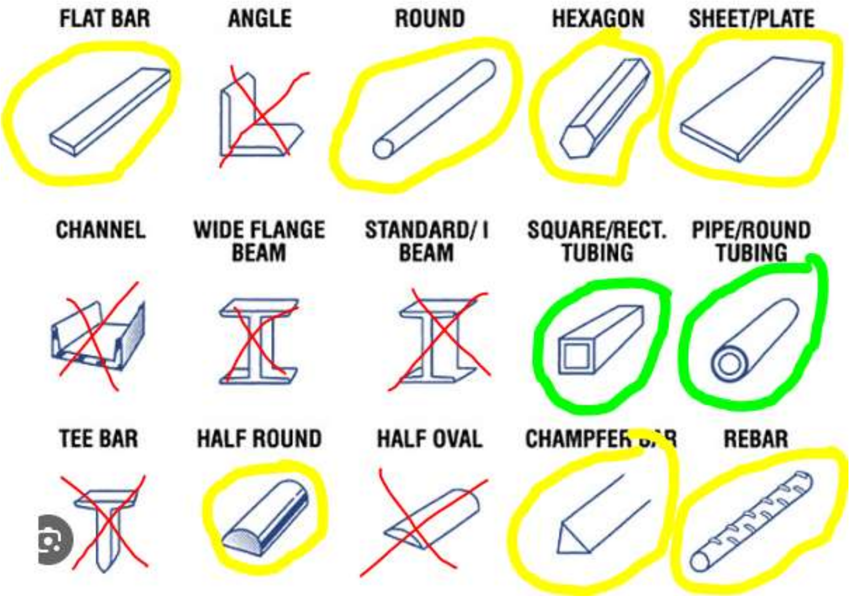
Stiffness/Rigidity vs. Shape (Contd.)

Don’t forget about torsion!!

Most of your arm segments will undergo some amount of torsion, and it will likely increase as you get closer to the base of the arm near the robot.

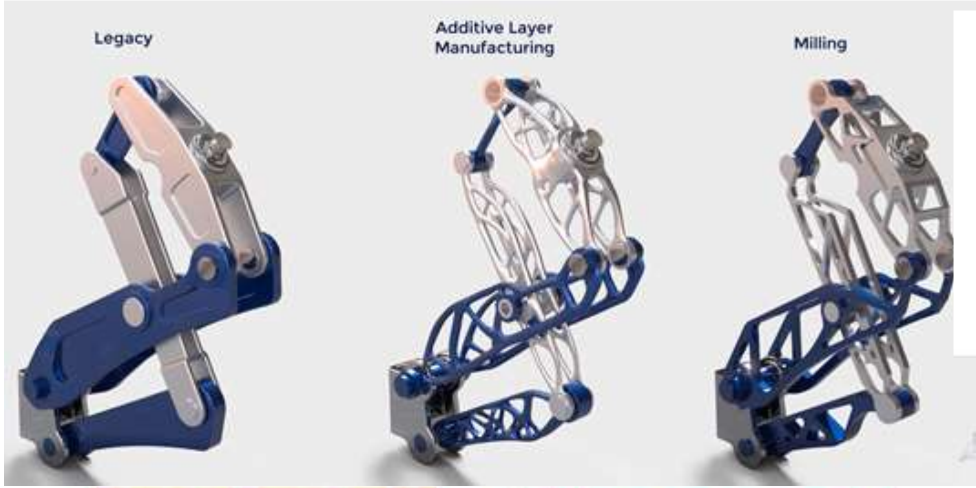
Tortional rigidity is best by getting as close as possible to a large thin-walled hollow cylinder around the axis of the segment.

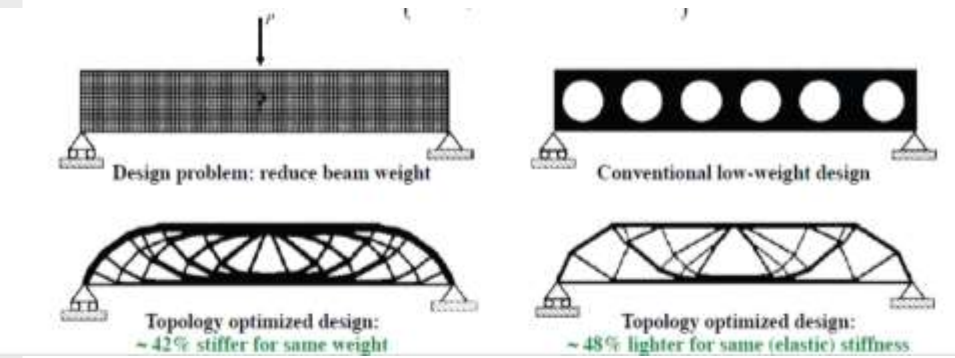
“L”, “I”, and “U” channel have decent bending strength, but almost no torsional rigidity.

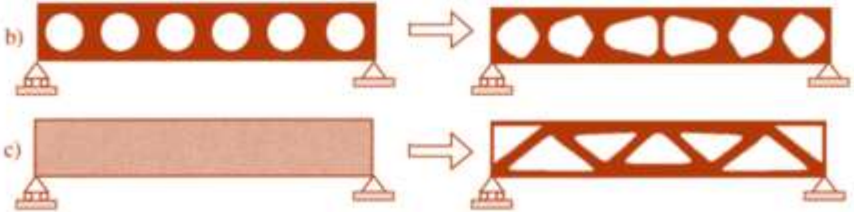


Shapes in Green are best for Torsion Compared to their bending rigidity. Anything with an opening along its length is weak in torsion by comparison.

Stiffness/Rigidity vs. Shape (Contd.)







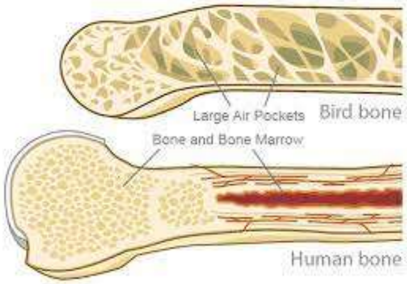
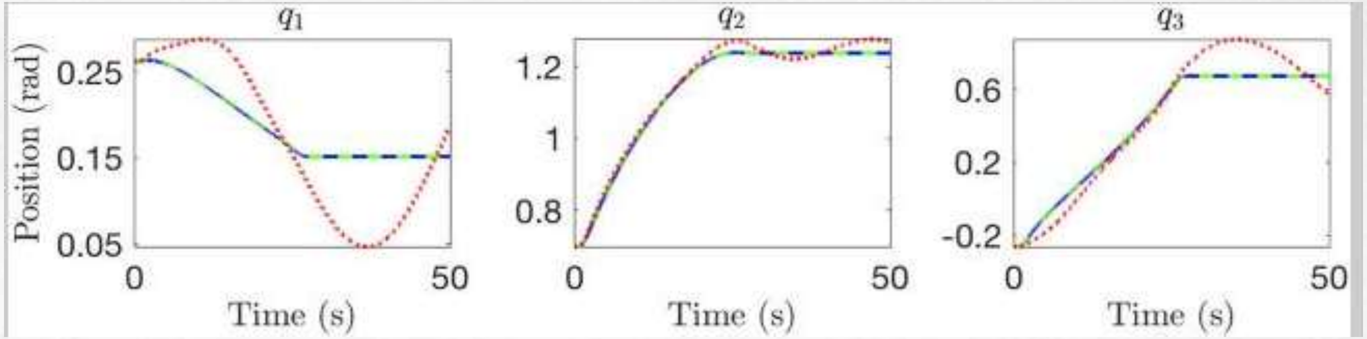


Illustration of a truss model and its different categories of structural optimization by: a) size, b) shape and c) topology (Bendsøe & Sigmund, 2003).

Controlling Oscillation with Damping

- Physical oscillation is the tendency of an object to move back and fourth past a point without additional input
- Damping is the reduction of oscillation of a system
- Physically this means removing energy from a system bring an object to a stop quickly.
- Settling time is the time before the system is stable at a new position. (we want this low)



Img Src: Trajectory Generation for Flexible-Joint Space Manipulators
https://www.ncbi.nlm.nih.gov/pmc/articles/PMC9009532/

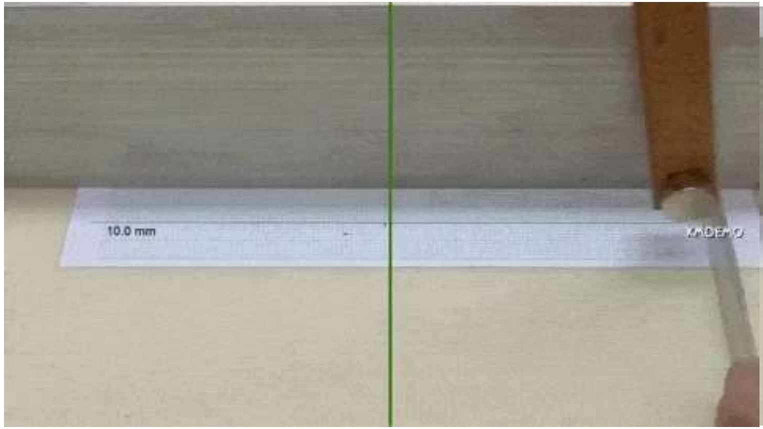
Controlling Oscillation with Damping

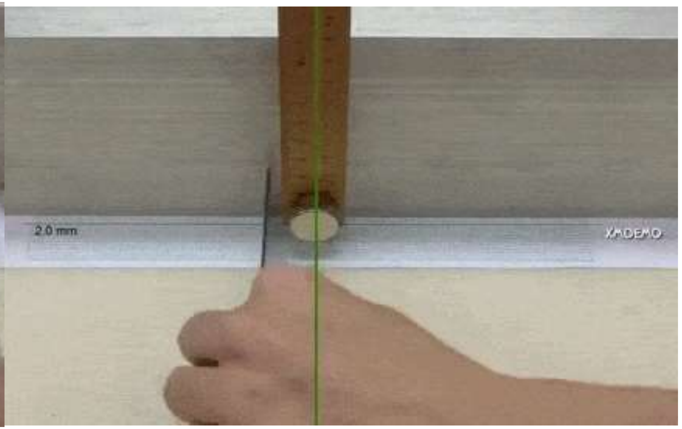
- **Controlling oscillation is particularly important when positional accuracy and speed are both important. (usually a goal of a robot competition)**
- **Most robots had minimal intentional damping in their design, and instead relied on the foam tiles through the body of their robot and incidental friction to stabilize their arms.**
- **This year, the target doesn't move, and precision is key so maximum speed will be more affected by robot oscillations.**

Key search terms: Underdamped, overdamped, critically damped, settling time

Types of Damping Techniques

- Some damping techniques that could be used in mechanical extension arms are:
  - Viscous damping
  - Frictional damping
  - Active damping
  - Tuned (or untuned) mass damping
- There is no time to really cover any detail on this subject





GIF src:
xmdemo.wordpress.com/

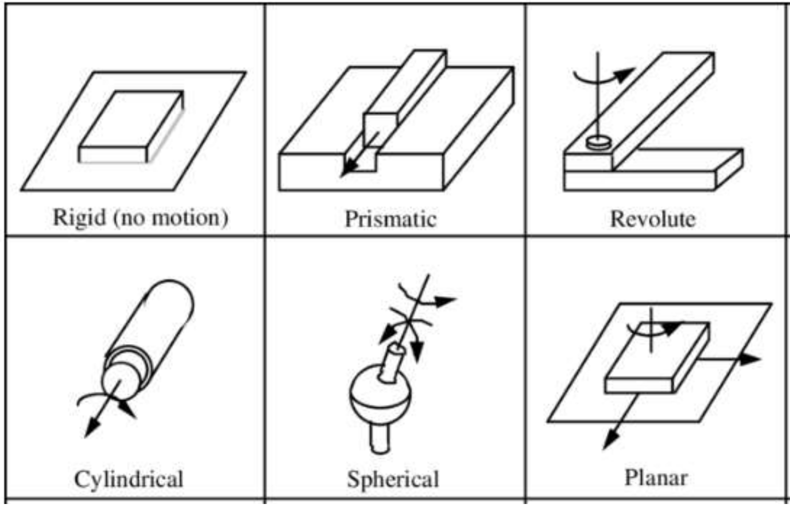
Types of Joints

Different types of joints commonly used in extension arms include:

- Revolute joints (hinges or elbows)
- Prismatic joints (sliders)
- Spherical joints (ball joints, rarely)

Joint design can obviously have significant effects on overall accuracy, precision, and load on the motors.

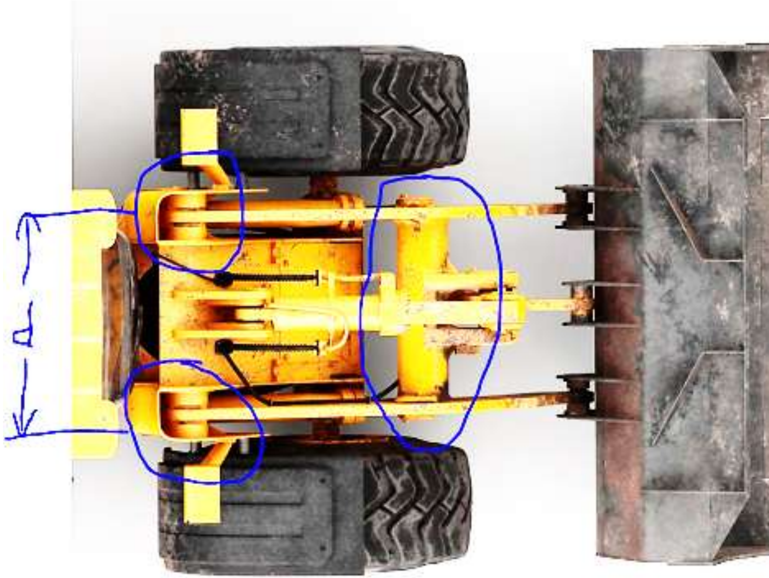
For all joints, the objective is to limit other degrees of freedom without increasing weight, size or friction more than necessary.



Precision and Accuracy in Joint Design

For Revolute (rotating) joints:

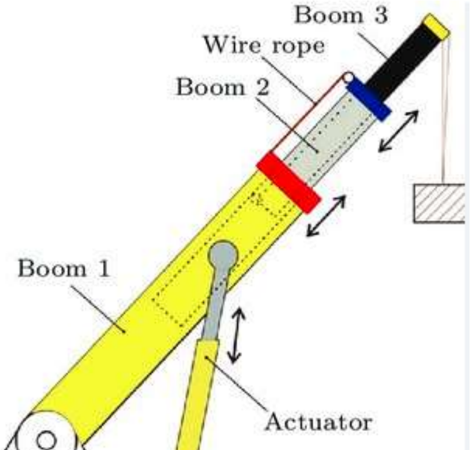
- **Making them as long as possible along their free axis reduces slop at the cost of size.**
- **Making the bearing radius larger increases strength, joint life, and stiffness with a corresponding cost to friction. (lubrication or ball bearings can help if needed).**
- **For joints with minimal cycles or <360 degrees rotation, ball bearings for arm revolute joints are generally overused in FTC. Some viscous friction in the joints can actually help with damping.**
- **Do not use bare steel on aluminum without a bearing!**



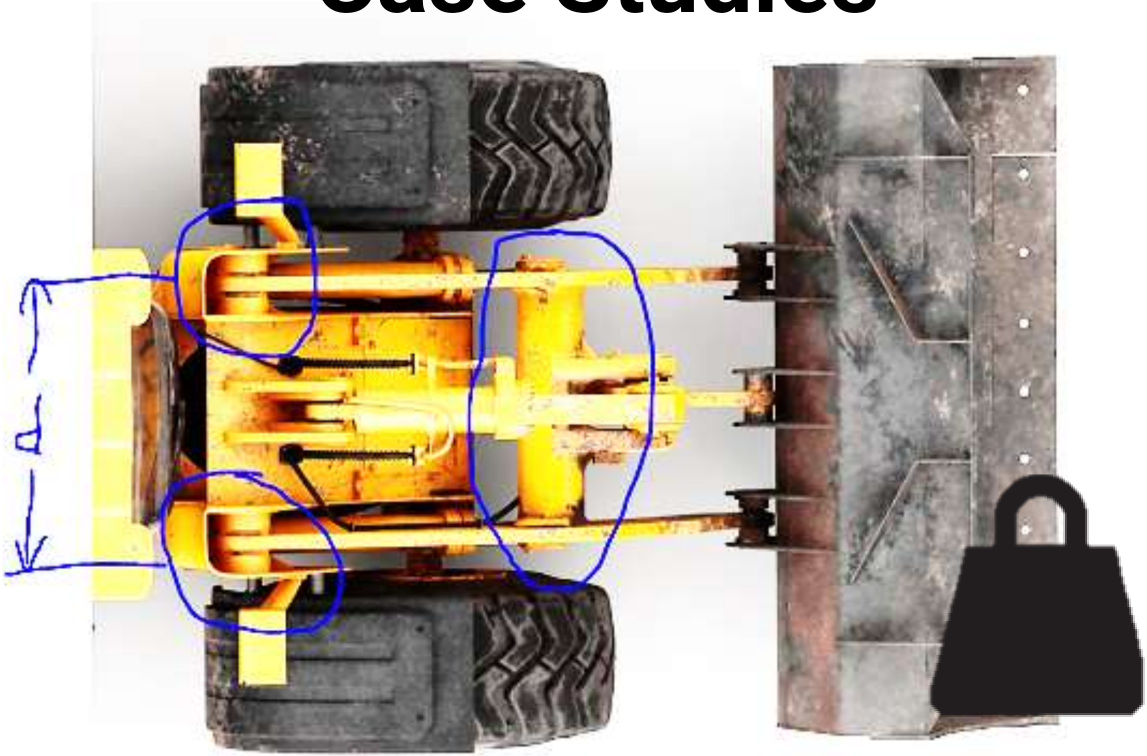
Precision and Accuracy in Joint Design

For Prismatic (sliding) joints:

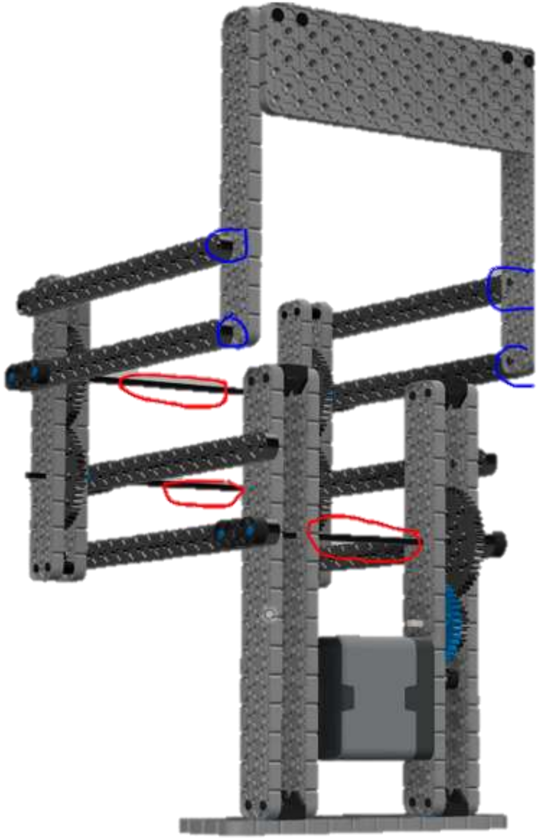
- **Making them as long as possible along their free axis also reduces slop at the cost of size and range of motion.**
- **Making the bearing surface larger increases strength, joint life, and stiffness <u>without</u> any corresponding cost to friction. (lubrication or bearings can help).**
- **Prismatic joints that are small, stiff, and move smoothly can be hard to make.**
- **They can be easily damaged with a small dent.**
- **Most of the force is concentrated near the ends of the contact regions in prismatic joints, this is where there needs to be reinforcement or appropriately sized roller bearings.**



Case Studies

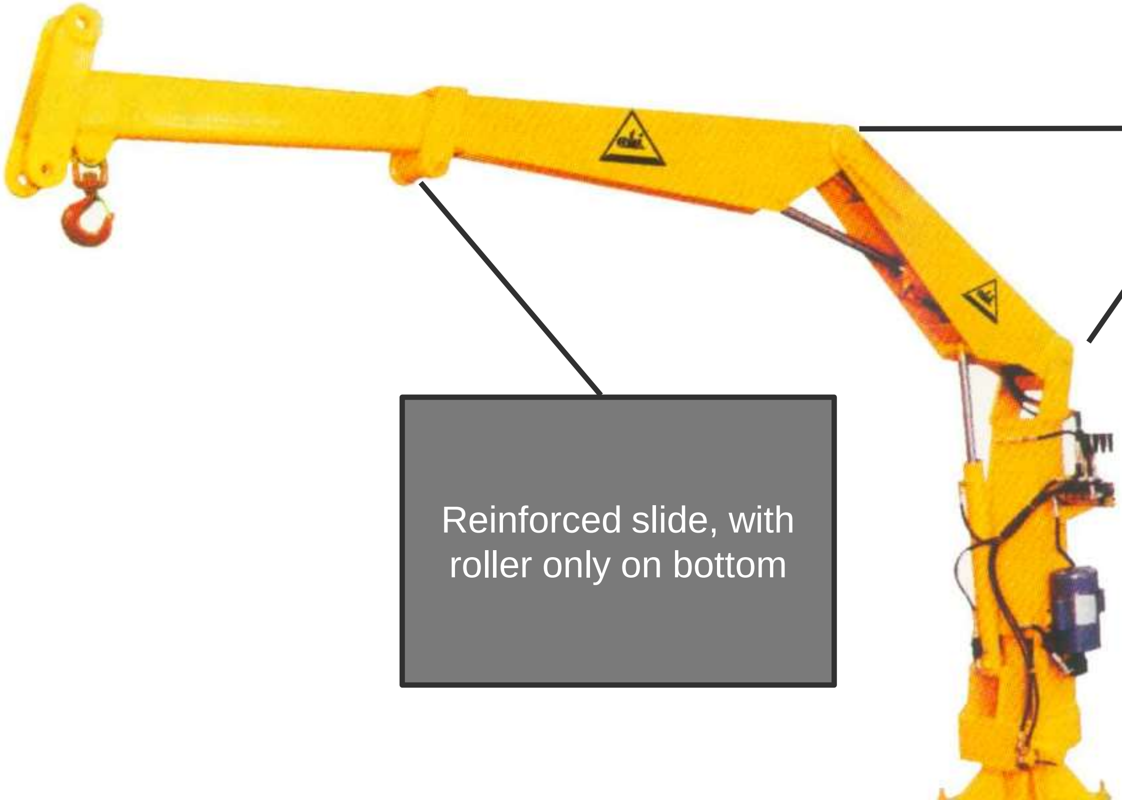


Case Studies



No significant torsional stiffeners between symmetric linkages like in the front end loader.

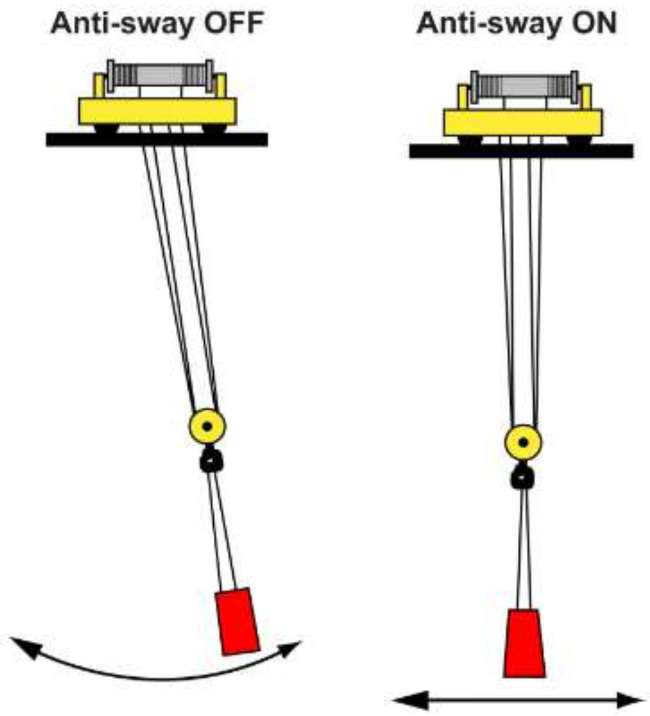
Case Studies

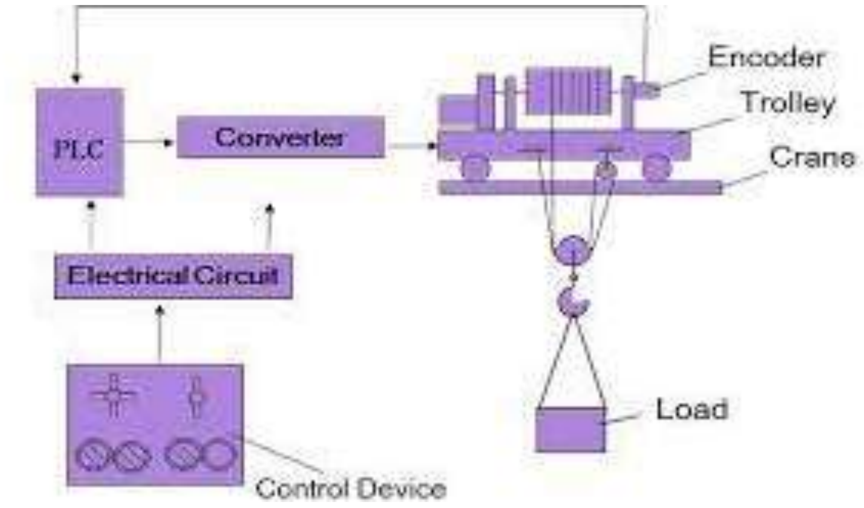


Revolute joints are widest parts of arm, and hydraulic actuator is as far as practical from joint axis

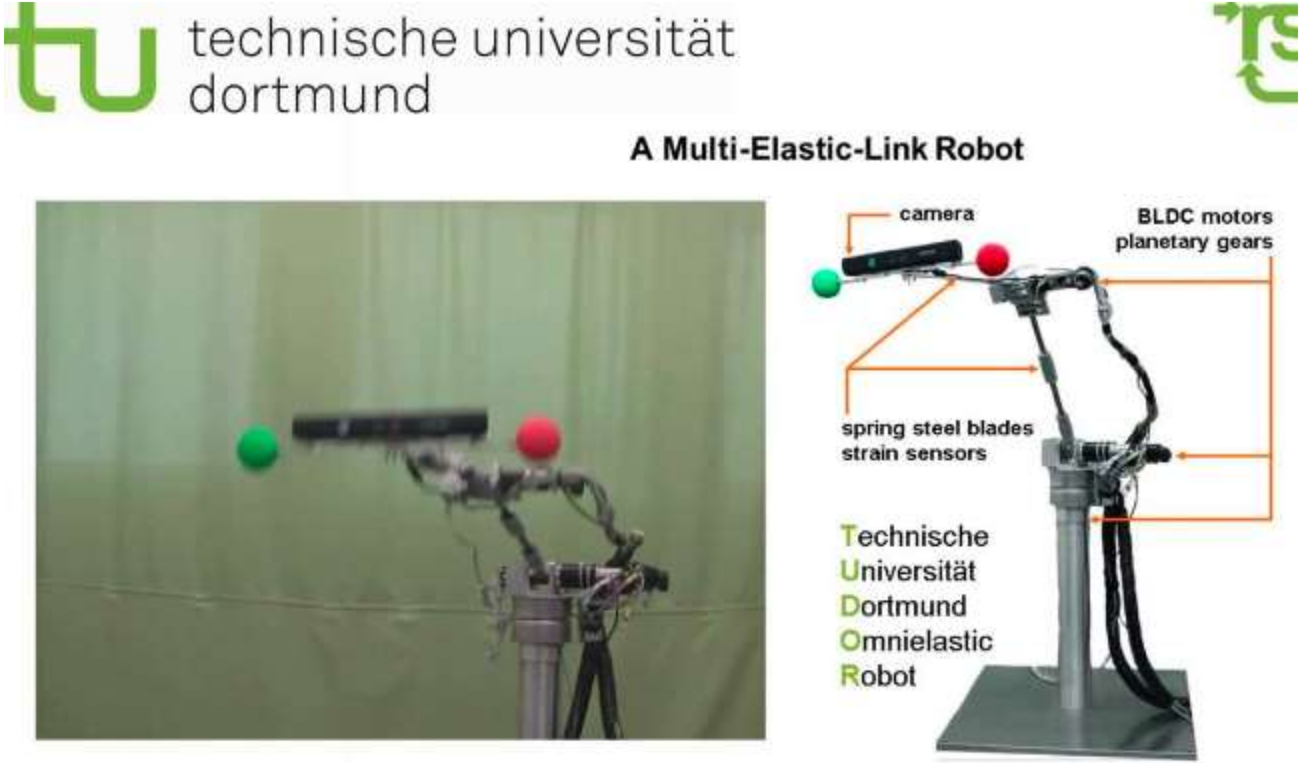
Reinforced slide, with roller only on bottom

Case Studies





Case Studies



This robot was intentionally designed to be as undamped as possible for the purpose of developing better control algorithms.

Case Studies

Case Studies

Force-Velocity Relation of Dampers in Horizontal Washing Machines | SpringerLink

Visit

Washing machines have a very simple damper design that doesn’t contain a liquid that can leak. This design is easy to build and good for FTC robots.

3D printing allows for simple and effective air based dampers too with a piston that fits loosely in a sealed sleeve.

Case Studies

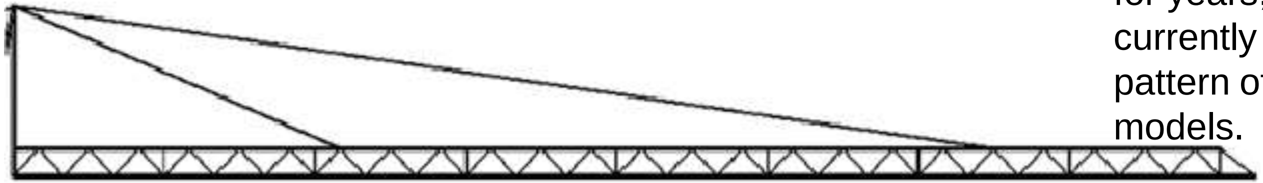
PROAIM Tri-Way Damper System for Vibration Isolator Shock Absorber Arm & 3-Axis Camera Gimbals| Stabilizes Roll-Tilt Errors from Moving ...

Amazon.com : PROAIM Airwave Vibration Isolator Shock Absorber Arm for 3-axis Camera Gimbals...

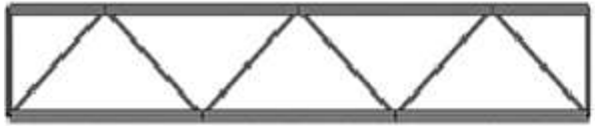
Visit

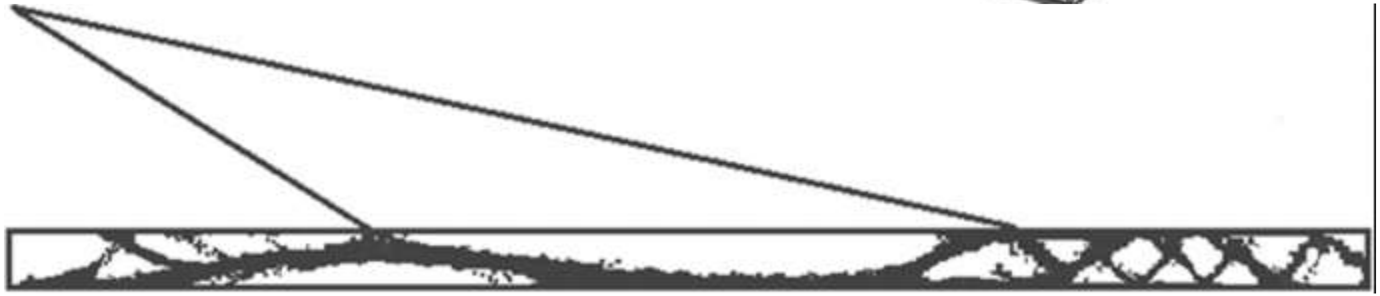
Case Studies

The simple truss has been a good enough tradeoff of strength to weight for years, and ease of manufacturing currently outweighs the bizarre pattern of the topologically optimized models.



Where possible, cables can provide a great source of additional stiffness.

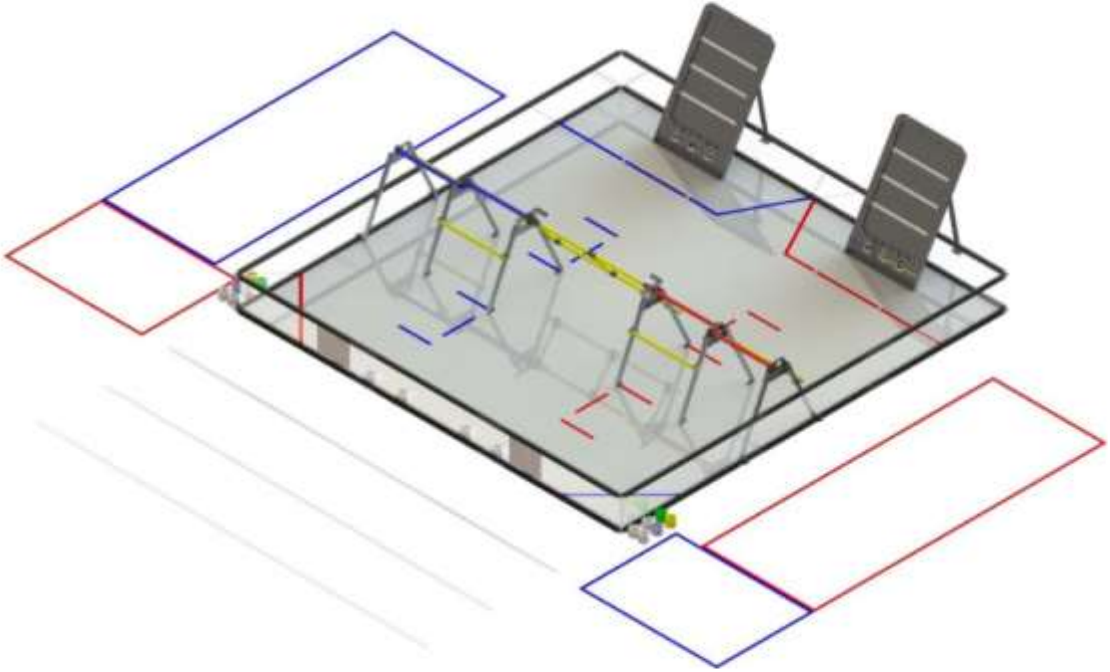


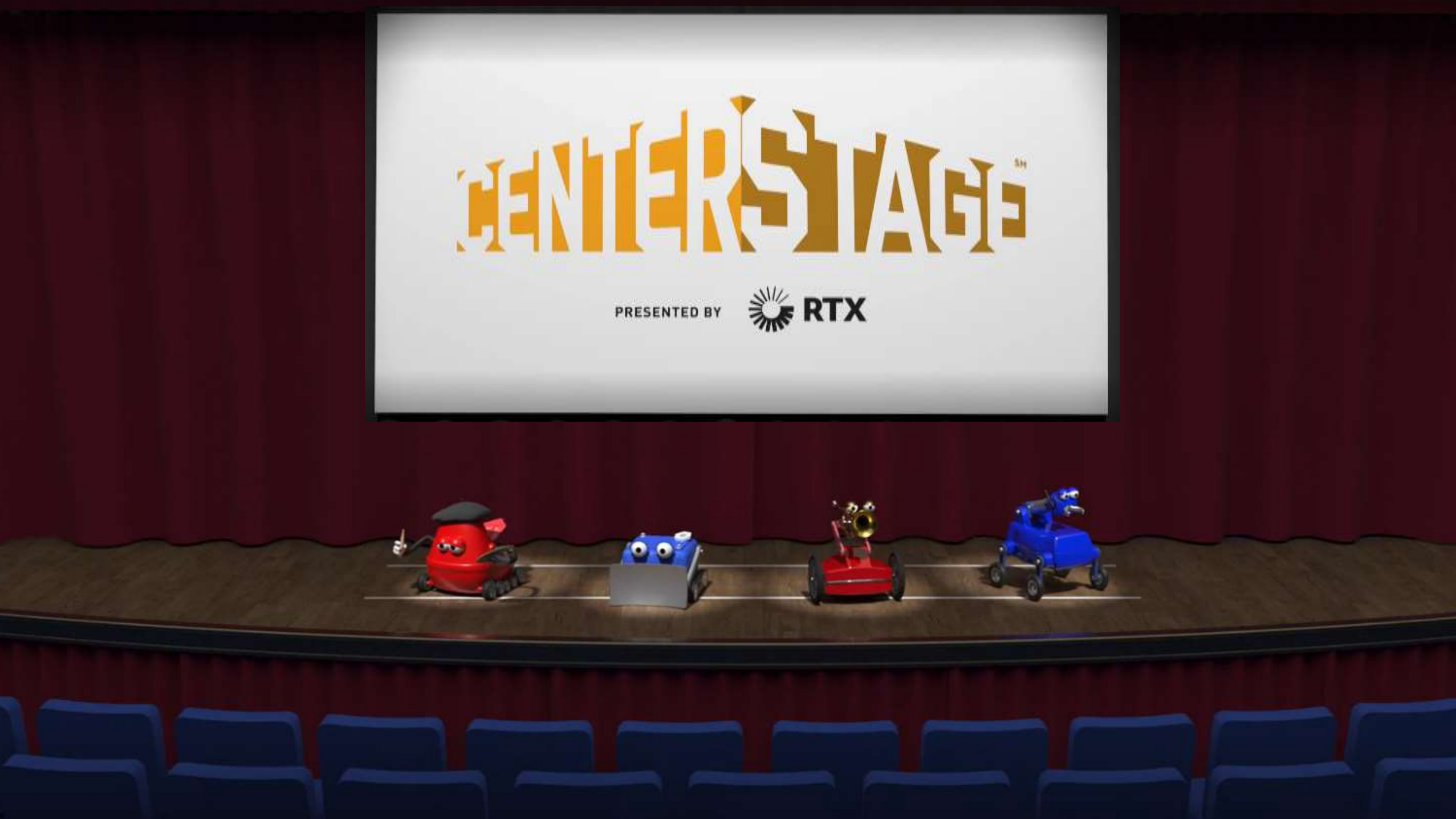


Case Studies

Hard to see, but sections are made of thin walled hollow steel rectangular tubing to maximize bending and torsional rigidity.

Questions?

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