CYSF Research Logbook

Note: My original logbook was written on paper
Title:
The Effect of Transmission Drive Mechanisms on the Load Capacity and Mechanical Stability of a Cardboard Parallel Gripper

WEEK 1: BACKGROUND RESEARCH & DESIGN

October 14

Project Brainstorming & Problem Identification

Today I finalized my project idea. I want to investigate how internal mechanism design affects robotic gripper performance.

Industrial and educational robots frequently use parallel grippers to handle objects in manufacturing and automation. However, many prototypes are built using lightweight materials like cardboard. I want to determine how mechanism choice affects load capacity and stability when using weak materials.

Testable Question

How do different internal mechanisms affect the mechanical handling and maximum load capacity of a cardboard parallel gripper?

October 15

1. Parallel Grippers

What is parallel gripper?

Parallel grippers use two jaws that move side by side to grab, hold, and release objects smoothly
The jaws move in sync, giving a stable grip without overcomplicating things. Fewer moving parts means fewer breakdowns. Parallel grippers usually have 2 fingers, but some 3-finger configurations are also out there. If it has 5 fingers, it's most likely not a parallel gripper.
Parallel grippers apply even pressure, making them ideal for jobs where slipping or uneven force would be a disaster.

While angular and adaptive grippers overcomplicate things, parallel grippers keep it clean and reliable.

Why jaws must stay parallel?
the jaws of a parallel gripper do not rotate; the gripper jaws move in a linear fashion, also known as straight-line motion, while maintaining their parallelism. This gives parallel grippers the ideal capability of grasping parts of a uniform shape and size, such as cylinders, blocks, or machined parts.

2. Four-Bar Linkage

What a four-bar linkage is

A four-bar linkage is a mechanical system made of four rigid bars connected in a loop by pivot joints that lets motion transfer from one link to another in a controlled way.

How it keeps motion controlled

Because the links are connected in a closed loop, moving one bar causes the others to move in a predictable path, controlling how the output motion (like opening claws) happens.

Why it is used in grippers

It keeps the gripper jaws moving in coordinated motion (often parallel) so they grip objects evenly without twisting or tilting.

Effect on jaw alignment
With a four-bar setup, the jaws stay aligned (parallel or consistent relative orientation) as they open/close, which helps grip objects securely.

3. Force and Load

Definition of force
Force is a push or a pull that can change an object’s motion or shape and is measured in newtons (N).

What load capacity means
Load capacity is how much weight or force a system can handle before it fails or slips.

Relationship between force and weight
Weight is the force of gravity acting on an object’s mass, greater mass means greater force due to gravity.

How grip force affects slippage
If the grip force isn't high enough to counteract the weight (and friction) of the load, the object will slip out.

4. Friction

What friction is
Friction is the force that resists motion between two surfaces in contact.

How friction helps objects stay gripped
Friction between the gripper and object prevents slipping, more friction means a more secure grip.

Cardboard vs other materials
Cardboard has a rough surface that can create more friction than smooth materials like plastic but less than rubber.

Factors that increase/decrease friction
Rougher surfaces, heavier normal force (push together), and texture increase friction lubrication, smoothness, and lower contact force reduce it.

5. Torque

Definition of torque
Torque is the measure of how much a force causes an object to rotate about a pivot.

How servo motors produce torque
Servos produce torque by applying force at a distance from the pivot in the motor's output shaft, turning it.

How torque affects gripping strength
More torque means the gripper can apply greater force to hold heavier loads before slipping.

Distance from pivot and torque
Torque increases with both force and the distance from the pivot point where the force is applied.

6. Servo Motors

What a servo motor is
A servomotor is a motor with a feedback system that can precisely control angular position.

Why servos are used in robotics
Servos are used because they can move to and hold specific angles accurately, which is useful for grippers and robotic joints.

How servos control angle and movement
They use a feedback sensor and control signal to rotate the output shaft to a commanded angle and hold it.

Limitations of servo strength
Servos can stall or not provide enough torque if the load is too heavy or binding is high also they can overheat.

7. Arduino and Coding

What an Arduino is
An Arduino is a small programmable microcontroller board used to control electronic components like servos.

Role of coding in controlling servos
Coding tells the Arduino *what to do* and *when to do it*. For servos, you write code that:

- includes a servo control library
- attaches the servo pin
- tells the servo what angle to move to

Why same code is used for fair testing

Using the same code for all trials ensures that the only thing changing between tests is the mechanism type not how the servo moves. With identical servo movement patterns, the comparisons between mechanisms are fair and scientifically valid.

8. Mechanical Advantage

Definition of mechanical advantage
Mechanical advantage is how much a machine multiplies the input force to do work on a load.

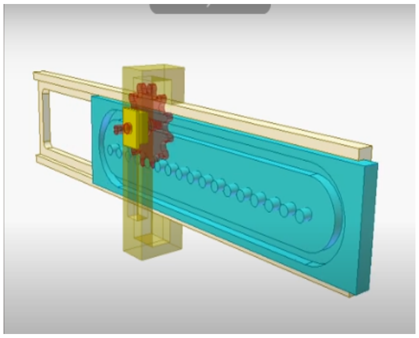
How mechanisms change force and motion
Mechanisms like linkages trade distance for force they can increase output force but decrease motion range

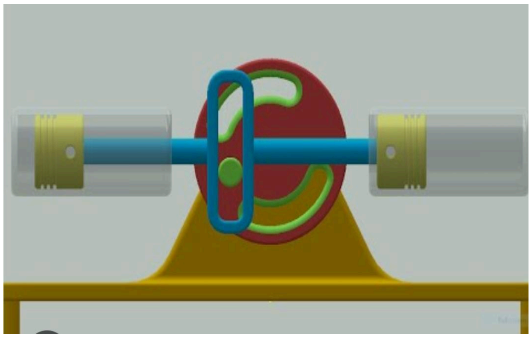
Why some mechanisms hold more weight
Mechanisms with higher mechanical advantage can convert small input forces into larger output forces, letting them hold heavier loads.

9. Mechanism Types (Overview) Bing videos are the exact model that will be used in the parallel gripper

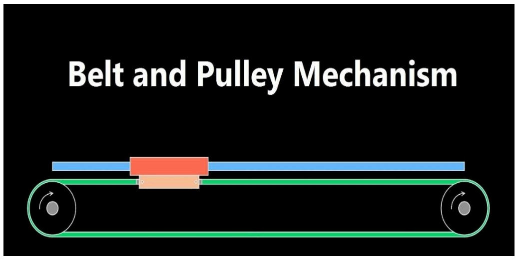
Pin/rack drive — how it works

A pin rack drive mechanism, commonly known as a rack and pinion system, converts rotational motion into linear motion through the interaction of a circular gear (the pinion) and a linear gear (the rack).





Scotch yoke mechanism — how it works
The Scotch yoke mechanism is a mechanical device that converts rotational motion into linear motion, or vice versa, using a slotted yoke and a pin.



Belt pulley mechanism — how it works
In belt drives, power is transmitted between at least two pulleys by a belt. One pulley drives the belt (*driving pulley*) and the other pulley is driven by the belt (*driven pulley*). In belt drives, the speed is often reduced, so that in these cases the smaller of the two pulleys is the driving pulley.

Diagram images all credits to owners

Pros and cons of each (basic)
pin/rack drive:rotational to linear motion, simple, precise, limited range although)

Scotch yoke:rotational to linear via slotted yoke simple, easy to prototype, but can bind cardboard)

belt-driven:pulleys + belt rotational to linear, smooth, flexible, can adjust speed, belts may slip or stretch, need maintenance if steered off the gear

Mechanism Description

Pin rack:

The red gear acts as the input component. Its shaft end slides inside the track-shaped slot of the cyan pin rack. Due to the forces made by the gear engagement, both the cyan pin rack and the yellow slider, which carries the red gear, move in a reciprocating motion.

Rotational motion from a stationary power source like the servo is transmitted to the red gear using suitable mechanisms such as a double Hooke's joint or an Oldham coupling.

Calculations

- Zr = Number of pins on the rack
- Zg = Number of teeth on the gear
- D = Diameter of the gear's rolling circle
- T = Pitch between the gear and rack
- S = Stroke length of the rack
- L = Length of the groove on the rack
- N = Number of gear revolutions required to complete one working cycle (one double stroke of the rack)
- $\pi = 3.142$

Scotch yoke

The crank (input shaft) acts as the input component. A crank pin mounted on the rotating crank engages with the straight slot of the yoke. As the crank rotates, the crank pin slides back and forth within the slot, forcing the yoke (slider) to move in a reciprocating motion along a straight guide.

Rotational motion from a stationary power source like a servo is transmitted directly to the crank through drive mechanisms. The rotation of the crank is therefore converted into linear reciprocating motion of the yoke.

Motion Calculations

- R = Radius of the crank (distance from crank center to crank pin)
- D = Diameter of the crank circle
- S = Stroke length of the slider (yoke)
- θ = Angular position of the crank
- x = Linear displacement of the slider from the center position
- N = Number of crank revolutions required to complete one working cycle (one double stroke of the slider)
- π = 3.142

Belt drive

The belt and pulley mechanism is used to convert rotary motion into linear motion. In this system, a belt is attached to a carriage at both ends, forming a closed loop that runs over two pulleys positioned at opposite ends.

One pulley acts as the driving pulley and is connected to an servo, while the pulley on the opposite side functions as an idler pulley, supporting and guiding the belt. When the driving pulley rotates, it moves the belt along its path. Since the carriage is fixed to the belt, the motion of the belt causes the carriage to move linearly along its guide.

The direction of the carriage movement depends on the direction of rotation of the driving pulley, allowing the carriage to move either forward or backward. To ensure reliable and slip-free motion transmission, timing (cogged) belts are often used instead of flat belts, and the pulleys are replaced with matching toothed pulleys.

This mechanism is widely used in automation systems, CNC machines, and positioning devices where controlled linear motion is required.

Motion Calculations

- Dp = Diameter of the driving pulley
- Rp = Radius of the driving pulley
- C = Circumference of the pulley
- S = Linear displacement of the carriage
- θ = Angular rotation of the pulley (in radians)
- N = Number of revolutions of the driving pulley
- π = 3.142

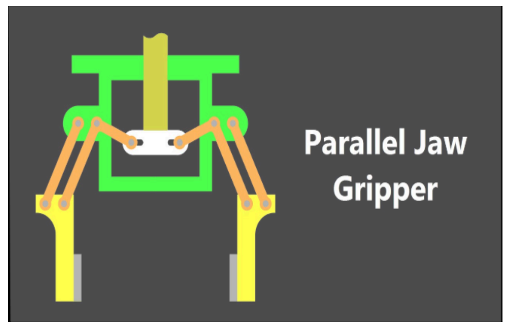
Hypothesis: Belt-Driven will perform best due to distributed load transfer.

Each has strengths in precision, durability, and load capacity.

10. Material Properties of Cardboard

Strength of cardboard

Cardboard is strong in compression but weaker in tension and bending compared to metals or plastics.



Flexibility and deformation
It bends more easily, which can help absorb forces but can deform under load if too weak.

Limits of cardboard under load
Cardboard will start to bend or collapse when the load exceeds its structural rigidity.

Why cardboard is good for prototyping
Cardboard is cheap, easy to cut, and quick to assemble, making it ideal for early design tests. Customised pieces, the original idea was to use lego, but lego may not have the specific pieces used for the primary mechanisms and make not fit into the rotations.

11. Engineering Design Process (iteration)

- Identify problem: Figure out what needs solving or improving
- Design & build: Create a prototype based on ideas
- Test & evaluate: Run experiments and collect data
- Improve design: Use results to make changes
- Repeat: Iterate steps until design meets requirements

WEEK 2 — DESIGN & CONSTRUCTION
October 22

Same design used:

Initial Design Sketches

Sketched full gripper:

- Identical cardboard claws
- Symmetrical four-bar linkage
- Single servo input
- Modular interchangeable mechanism base

- Controlled design:
  Only the primary mechanism changes.

October 23

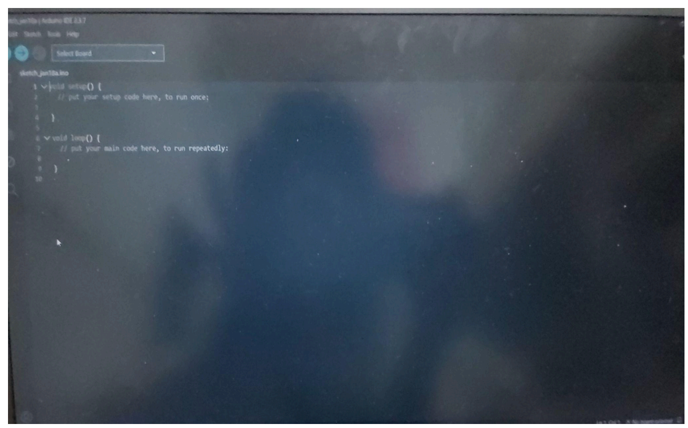
Material Preparation:

Cardboard

Using bamboo skewers as pivots.

Observed:
Cardboard bends slightly under lateral pressure.

October 24



Building Pin/Rack Prototype

Assembled Pin/Rack mechanism.

Observations:

- Motion smooth at low load
- Slight flexing at rack interface
- Gear teeth compress slightly under torque

Uploaded Arduino code and confirmed consistent servo rotation.

October 25

Building Scotch Yoke Prototype

Constructed slotted yoke system.

Observed:

- Increased friction at slot
- Resistance when rotating under load
- Minor binding even without weight

Concern: friction losses may reduce performance.

October 26

Building Belt-Driven Prototype

Installed LEGO belt wheel and nylon yarn belt.

Observations:

- Smooth rotation
- Even tension across both sides
- Minimal friction points

This design appears mechanically efficient.

WEEK 3 — TESTING & DATA COLLECTION

October 28

Pin/Rack Testing Final Mechanism

Tested loads from 0.2 kg upward in 0.2 kg increments.

Results:
Held steadily up to 1.6 kg
Slipped at 1.8 kg

Observations:

- Slight jaw misalignment near failure
- Minor bending at gear interface
- Increased servo strain at high load

Failure cause:
stress concentration and minor torque loss.

October 29

Scotch Yoke Testing Final Mechanism

Results:
Held to 1.2 kg securely
Slipped at 1.4 kg

Observations:

- Binding at slot-pin interface
- Increased jaw misalignment
- Noticeable cardboard deformation

Failure cause:
High friction and uneven force transfer.

October 30

Belt-Driven Testing Final Mechanism

Results:
Held all loads up to 2.0 kg (maximum tested)
No slippage observed

Observations:

- Consistent jaw parallelism
- Minimal deformation
- Smooth force transfer

Likely improved performance due to:

- Distributed torque
- Reduced stress concentration
- Lower internal friction

November 1
Data Analysis

Trend:
Scotch Yoke < Pin/Rack < Belt-Driven

Load Capacity Comparison:

1. Scotch Yoke: 1.4 kg
2. Pin/Rack: 1.8 kg
3. Belt-Driven: 2.0 kg

Performance correlates with:

- Reduced friction
- Even torque distribution

- Mechanical advantage efficiency

November 2

Conclusion

The hypothesis was supported.

Changing the internal mechanism significantly altered performance.

The Belt-Driven mechanism demonstrated:

- Highest load capacity
- Best jaw alignment
- Least deformation

Engineering explanation:
Distributed force reduces localized stress and maintains four-bar linkage geometry under load.

November 3

Improvements & Future Research

Improvements:

- Reinforce cardboard with laminated layers
- Add low-friction bushings at pivots
- Strengthen rack teeth
- Optimize yoke slot clearance

Future Research:

- Test stronger servo motors
- Analyze torque using sensors
- Compare materials (plastic vs cardboard)
- Measure coefficient of friction experimentally
- Test irregular object shapes
- Study fatigue over repeated cycles

Applications:
Robotics

Automation
Manufacturing
Educational prototyping