DIMENSIONAL SYNTHESIS AND KINEMATIC MODELING OF NOVEL FIVE-BAR MECHANISMS WITH VARIABLE TOPOLOGY

MSOE UNIVERSITY

Myles Pratt, Rachael Klamecki, Erik Sakuma

Advisor: Dr. Brian Slaboch

WISCONSIN SPACE GRANT CONSORTIUM WSGC

ABSTRACT

Industrial pick-and-place systems commonly rely on multiple actuators to achieve translational and rotational motion, increasing complexity and power consumption. This work presents a one-degree-of-freedom mechanism with variable topology (MVT) for planar pick-and-place tasks. The proposed five-bar mechanism incorporates a variable joint that switches between prismatic and revolute modes, enabling both translational and rotational motion using a single actuator. The mechanism is analyzed through topology and kinematic modeling, supported by design software and validated with a fabricated prototype. Results demonstrate reduced system weight, power, and cost compared to conventional multi-actuator designs.

GOALS

Goal 1: Kinematic Modeling
Develop and validate the kinematic equations governing a novel Five Bar Mechanism with Variable Topology that allows for translational and rotational movement in the same plane to pass through three defined points.

Goal 2 : Simulation & Design Tool Development
Develop a MATLAB-based GUI that automatically synthesizes a five-bar MVT capable of reaching three user-defined target points, generates feasible geometric configurations, and provides animated motion visualization of the resulting mechanism. This allows for quick mechanism generation from designers.

Goal 3 : Physical Prototype
Design, fabricate, and test a physical prototype of the synthesized mechanism in collaboration with the University Mechanism Design Club to experimentally validate the kinematic model and demonstrate the MVT concept in practice.

MVT DEFINITION

Mechanisms that intentionally change their kinematic topology during operation

- Type of Joint (e.g. revolute vs prismatic)
- Which joints are active.
- Degrees of freedom.

The topology change may be caused by motion constraints, singularity configurations, or an external input. Allows for complex, multi-phase movement using fewer actuators by reusing the same actuator across different topology states.

Type I – Configuration Induced

- The mechanism passes through a singular configuration, resulting in a permanent change in global degrees of freedom.
- Also called "Kinematotropic" mechanisms.

Type II – Joint Geometry Change

- Topology changes due to a change in joint geometry.
- The joint geometry allows the mechanism to change between joint types (e.g., revolute to prismatic) or adjust its motion direction.

Type III – External Constraint

- Topology changes due to an externally applied constraint (e.g., mechanical stop, latch, or lock).
- The external constraint actively modifies the degrees of freedom during operation.
- Often categorized as metamorphic or reconfigurable mechanisms.

MOTIVATION

Industrial automation continues to demand robotic systems that are lighter, more energy-efficient, and capable of high-speed, high-reliability operation.

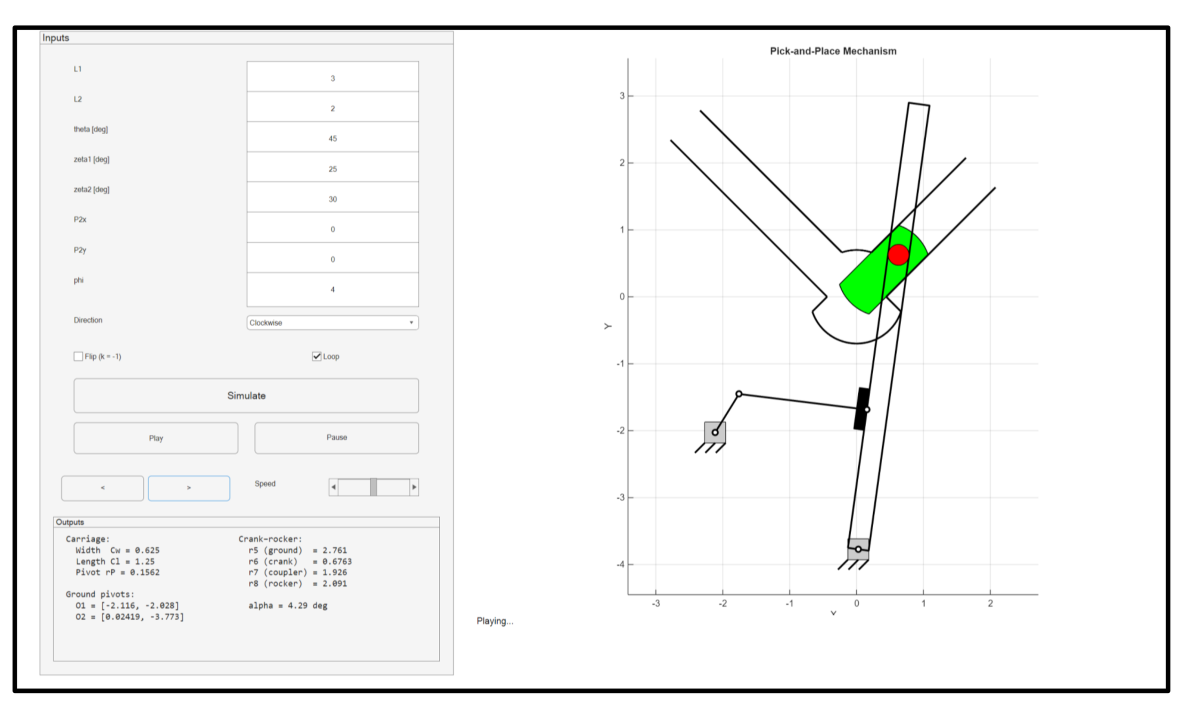
Common solutions require **multiple actuators** for translation, rotation, and grasping. Multiple actuators increase mass, cost, power consumption, and control complexity.

Secondly, space manufacturing systems are severely constrained by mass, volume, and power. Electric motors account for over 60% of industrial energy consumption [1]. Reducing the number of actuators directly reduces:

1. Power usage **2. System Mass** **3. Failure points**

DESIGN TOOL

An open-source mechanism design tool was created to assist mechanism designers in synthesizing the five-bar MVT for application-specific requirements. This is believed to be the first open-source software available for dimensional synthesis of MVTs.



This tool allows users to define mechanism position and motion through input parameters, which are then visualized in an interactive simulation with play/pause controls, speed adjustment, and frame-by-frame viewing. The tool also outputs data that can be used for prototype fabrication or further parameter analysis.

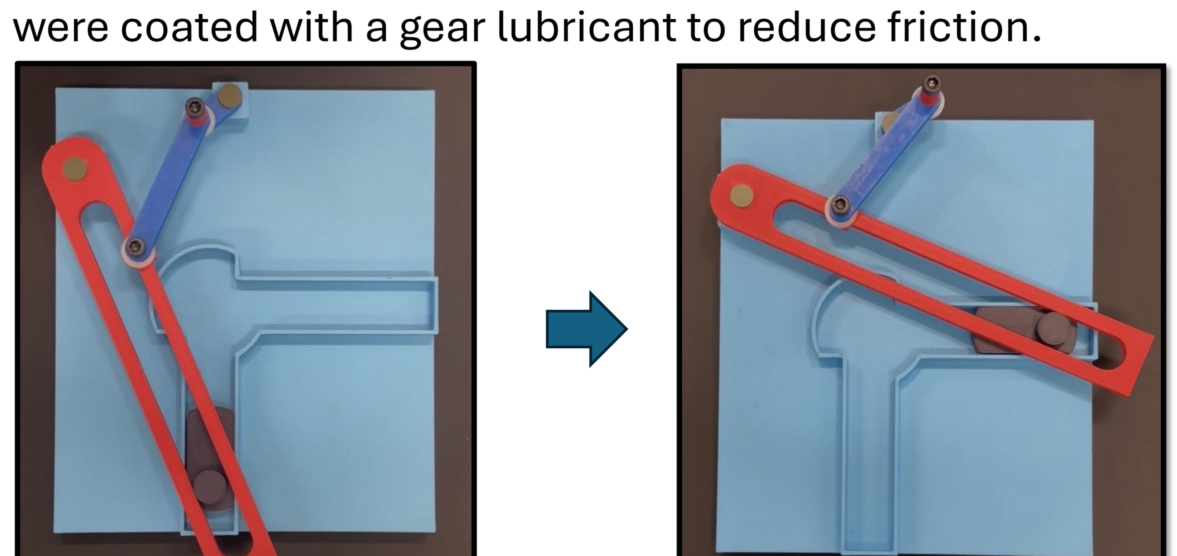
PHYSICAL PROTOTYPE

The MATLAB-based GUI was used to determine the track geometry and the link lengths of the five-bar MVT to reach the three user defined target points.

The dimensions of the track and the link lengths were then used to model the necessary components in SolidWorks.

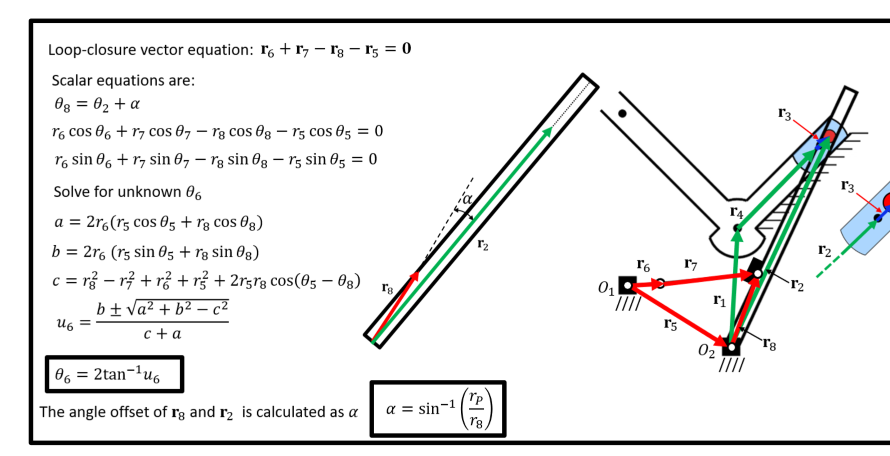
The track, links, carriage, and ground pivot pins were 3D printed out of PLA. M6 bolts and Nyloc nuts were used to form connections between the input, output, and coupler links.

To ensure smooth operation, the sides of the carriage were coated with a gear lubricant to reduce friction.

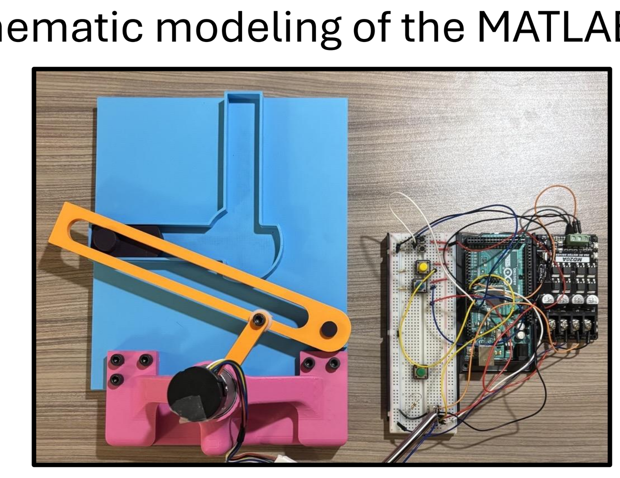


MILESTONES

1. Conceptualized a novel mechanism that achieved three distinct motion states through geometric intuition and validated the concept using an early-stage 3D-printed prototype.
2. Developed an initial MATLAB simulation that computes track geometry and carriage geometry from user-defined target points
3. Derived and implemented the kinematic model of the mechanism, including velocity and acceleration analyses to assess motion smoothness, timing, and dynamic feasibility.



4. Created a 3D printed initial prototype with a hand crank and later incorporated a motor input to validate the kinematic modeling of the MATLAB-based GUI



5. Created a GUI-based mechanism design tool that automates geometry synthesis, simulation, and visualization from user-defined input points.
6. Currently developing a machined prototype that incorporates high precision linear rails and a gripper.

NOTABLE REFERENCES

[1] Perrat, A., 2016, Energy Efficiency of Machines: The Smart Choice of Motorization, Schnieder Electric.

[2] B. Slaboch and P. Voglewede, "Mechanism State Matrices for Planar Reconfigurable Mechanisms," Journal of Mechanisms and Robotics, vol. 3, February 2011. doi: https://doi.org/10.1115/1.4003270.

[3] S. Surati, S. Hedaoo, T. Rotti, V. Ahuja, N. Patel, "Pick and Place Robotic Arm: A Review Paper," International Research Journal of Engineering and Technology (IRJET) February 2021.

[4] S.A. Joshi, C. Amarnath, Y.R. Rawat, Synthesis of variable topology mechanisms for circuit breaker applications. In Proceedings of the 8th NaCoMM Conference, IIT, Kanpur, 1997.

ACKNOWLEDGEMENTS

This work was funded by the generous support of the Wisconsin Space Grant Consortium under award agreement# UGR25_5-0.

The authors also acknowledge the MSOE Mechanism Design Club for their collaboration and contributions to the development and fabrication of the mechanism prototype.

CONTACT INFO

Myles Pratt: prattm@msoe.edu
Rachael Klamecki: klameckir@msoe.edu
Erik Sakuma: sakumae@msoe.edu