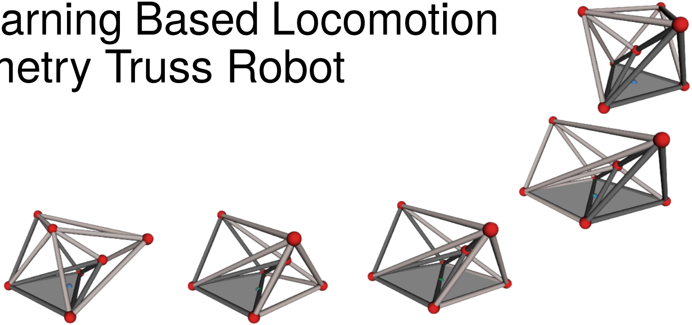
# Reinforcement Learning Based Locomotion for Variable Geometry Truss Robot



**Ozgur Gulsuna**

*10 Mar 2024*

ODTÜ METU **MMI**706 **Reinforcement** Learning

# Outline

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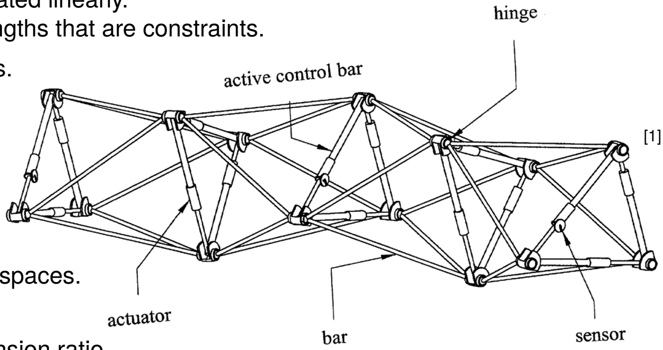
# Variable Geometry Truss Topology



Variable geometry topology (VGT) is a truss structured system that comprises actively actuated linear trusses linked with passive rotational ball joints.

- **Members:** Edges that are actuated linearly.
  has minimum and maximum lengths that are constraints.
- **Nodes:** Passive rotational joints.
  Angles between the members on joints are constrained.

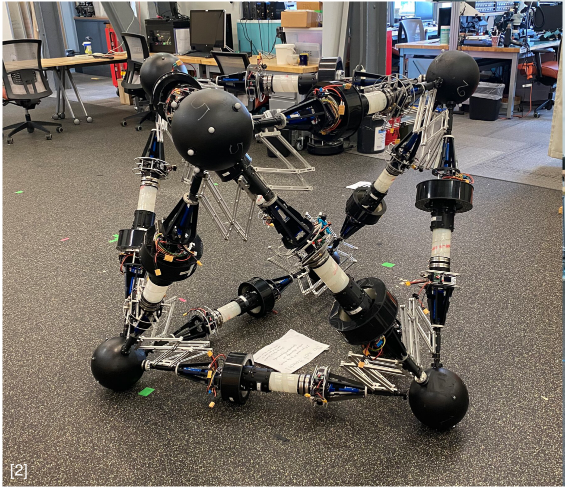



[1]

*Advantages:*
Variable size, pass-through confined spaces.

*Disadvantages:*
Needs a rigid actuator with high extension ratio.

# Realized Robots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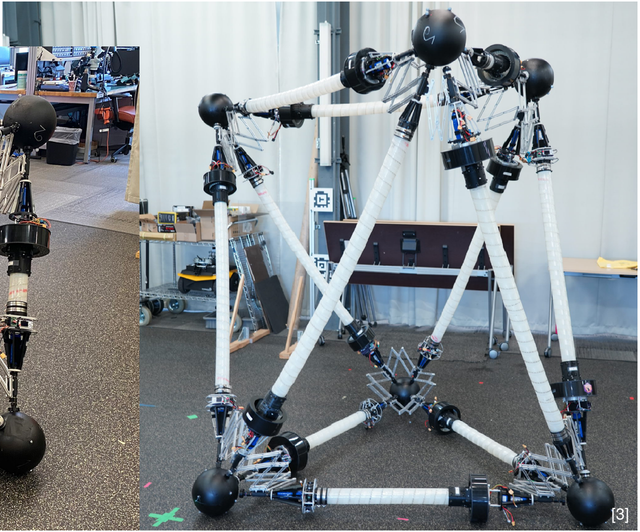
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# Realized Robots

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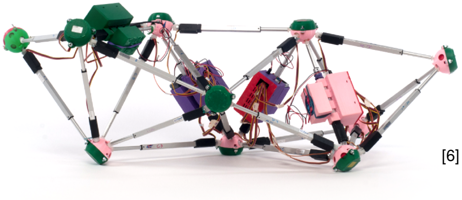

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# Outline

1. Domain
2. Research Question
3. Literature Review
4. Methodology & Algorithms
5. Risks & Limitations
6. Contributions & Future Work

# Locomotion Strategy for the VGT Robot

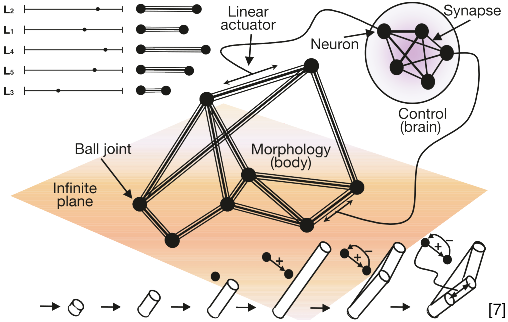


*Development of a reinforcement learning based locomotion strategy for truss robots.* This involves coordinating the movement of various parts in a specific sequence, similar to how serpents or mammals move, where intricate coordination is necessary.

Idea Development

The structure consists of $\mathrm{N}$ linear actuators, each with a single degree of freedom $(\mathrm{DoF})$, interconnected with passive joints.

1. *Model-Based/Free RL:* Single topology, baseline for comparison.
2. *Modular Control Policy RL:* Multiple topology, generalizability.
3. *Multi-Agent Policy RL:* Each member is an individual agent.



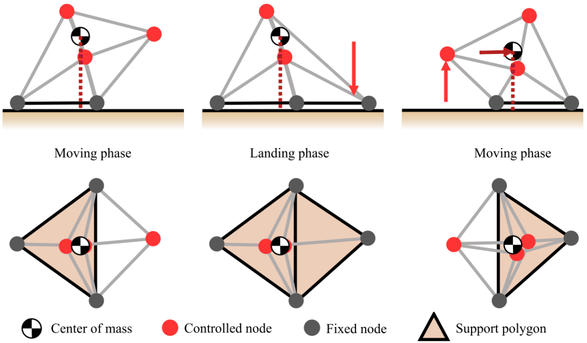

[7]

# Outline

# [Non-impact Rolling Locomotion of a Variable Geometry Truss]

[2019]

The velocity of nodes is optimized to move the center of mass given the desired velocity. The member velocities are calculated and actuated accordingly.[8]

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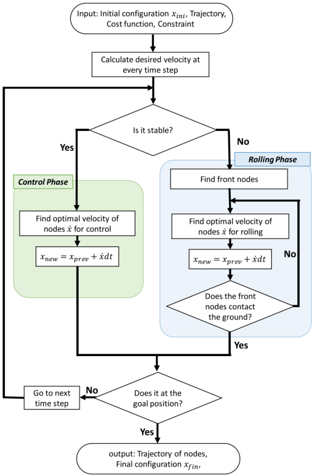
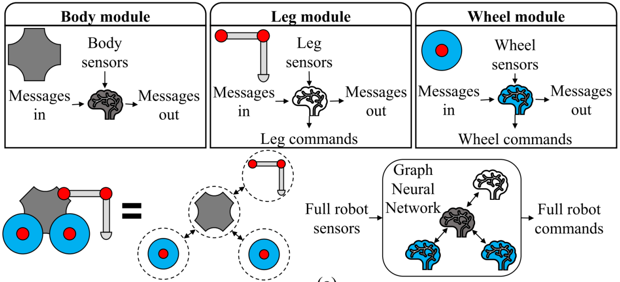



[9]

# [Learning Modular Robot Control Policies]

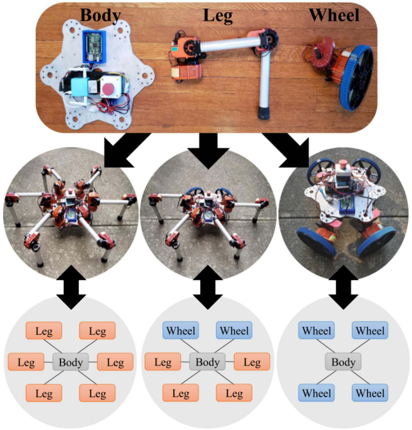
[2023]

Modular robots need specific control policies for each design, which becomes impractical for scalability. A modular policy framework allows for a single training process to adapt to various hardware arrangements and control different designs efficiently.[11]




(a)

[11]

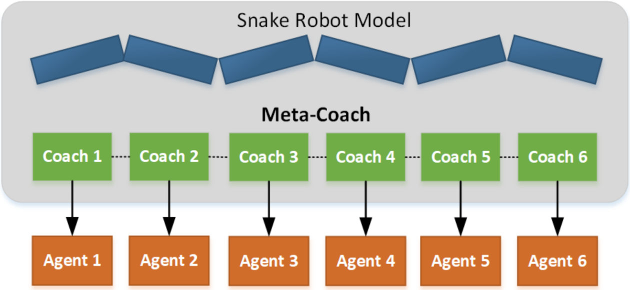



[11]

# [Distributed Coach-Based RL Controller for Snake Robot Locomotion]

[2022]

Snake robot control with RL is underexplored due to high freedom redundancy. Existing methods use asynchronous joint state representations. A new solution introduces a distributed coach-based learning approach to address these challenges.[12]




[12]

[13]

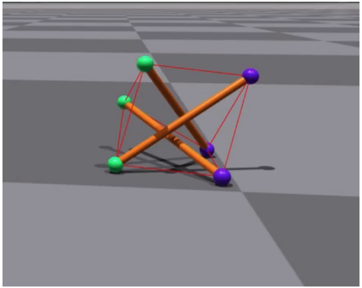
# Outline

# Developmental Procedure



Training simulations will be conducted in NVIDIA® Isaac Gym, where diverse truss robot models, including the inverse kinematics, will be modeled.

- Start with a simple VGT robot, such as a Tetrahedron.
- Begin in a uniform flat environment:
  - No obstacles (static/dynamic)
  - No terrain features
- Use only proprioceptive sensors and pseudo sensors:
  - All measurements are assumed accurate
  - No point cloud data
  - No visual feedback



**Algorithms:** Various PPO implementations are available, but they are often targeted for specific applications. A modified PPO implementation is anticipated.[14]

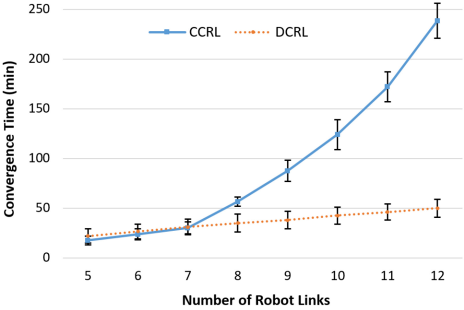
# Outline

# Assessing the Feasibility



For large-scale robots with numerous linear actuators, convergence times are anticipated to increase rapidly. An octahedral robot, composed of 12 members, essentially mirrors a quadruped robot. Scaling effort necessitates a broader approach. This observation is also mentioned in [12].

- Self collision check required, some truss typologies confine themselves.
- Ground contact sensing might be needed.
- Alternative simulation environments,
  - MuJoCo
  - RaiSim
- Modular control policy approach might increase the input size even further.
- Proper reward mechanism design leads to more advanced locomotion.

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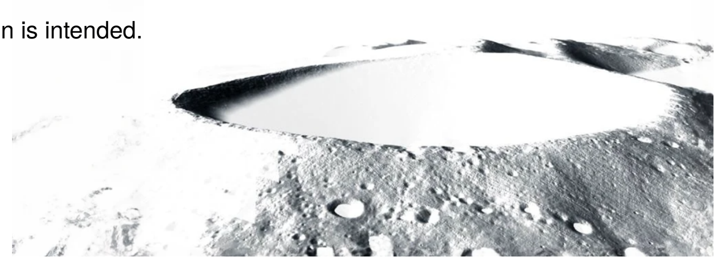
# Contributions & Future Works

- Assess the applicability and scalability of reinforcement learning methods across truss robots of different sizes and topologies.
- Evaluate and document the generalizability of the pipeline for robots with various topologies.
- Adapt locomotion and path planning strategies to navigate irregular, non-planar terrains.
- Tensegrity robot locomotion is intended.



# Bibliography I

[1] R. Avilés, G. Ajuria, E. Amezua, and V. Gómez-Garay, "A finite element approach to the position problems in open-loop variable geometry trusses," *Finite Elem. Anal. Des.*, vol. 34, p. 233–255, feb 2000.

[2] R. Guan, "Variable topology trusses (vtt)." https://runingguan.com/portfolio/vtt .

[3] G. Lab, "Variable topology trusses (vtt)." https://www.grasp.upenn.edu/projects/variable-topology-trusses-vtt/ .

[4] S. S. Lab, "An untethered isoperimetric soft robot." https://shape.stanford.edu/ .

[5] W. Bondin, "Morphs." https://vimeo.com/user16010993 , https://www.youtube.com/WilliamBondin .

[6] R. L. Read and A. Baskaran, "Controlling a variable geometry truss tetrobot with an isomorphic puppet controller," in *2020 2nd International Conference on Artificial Intelligence, Robotics and Control*, AIRC'20, (New York, NY, USA), p. 38–42, Association for Computing Machinery, 2021.

# Bibliography II


[7] H. Lipson and J. B. Pollack, "Automatic design and manufacture of robotic lifeforms," *Nature*, vol. 406, p. 974–978, Aug. 2000.

[8] N. Usevitch, Z. Hammond, S. Follmer, and M. Schwager, "Linear actuator robots: Differential kinematics, controllability, and algorithms for locomotion and shape morphing," in *2017 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, pp. 5361–5367, 2017.

[9] S. Park, E. Park, M. Yim, J. Kim, and T. W. Seo, "Optimization-based nonimpact rolling locomotion of a variable geometry truss," *IEEE Robotics and Automation Letters*, vol. 4, no. 2, pp. 747–752, 2019.

[10] S. Park, J. Bae, S. Lee, M. Yim, J. Kim, and T. Seo, "Polygon-based random tree search planning for variable geometry truss robot," *IEEE Robotics and Automation Letters*, vol. 5, no. 2, pp. 813–819, 2020.

[11] J. Whitman, M. Travers, and H. Choset, "Learning modular robot control policies," *IEEE Transactions on Robotics*, vol. 39, no. 5, pp. 4095–4113, 2023.

# Bibliography III

[12] Y. Jia and S. Ma, "Distributed coach-based reinforcement learning controller for snake robot locomotion," in *2022 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, pp. 1231–1238, 2022.

[13] K. Qiu, H. Zhang, Y. Lv, Y. Wang, C. Zhou, and R. Xiong, "Reinforcement learning of serpentine locomotion for a snake robot," in *2021 IEEE International Conference on Real-time Computing and Robotics (RCAR)*, pp. 468–473, 2021.

[14] F. Shi, T. Homberger, J. Lee, T. Miki, M. Zhao, F. Farshidian, K. Okada, M. Inaba, and M. Hutter, "Circus anymal: A quadruped learning dexterous manipulation with its limbs," 2020.

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Thank you for listening