Discussions on

Polygon-Based Random Tree Search Algorithm for a Size-Changing Robot

Jangho Bae [2], Sumin Park [4], Mark Yim [2], and TaeWon Seo [1]

10 Dec 2023

Presenter: Ozgur Gulsuna [3]

한 양 HANYANG UNIVERSITY 1939

Penn UNIVERSITY of PENNSYLVANIA

ODTÜ METU

Outline

1. Variable Geometry Truss Robot (VGT)

2. Non-Impact Rolling Locomotion

3. Polygonal-RRT Path Planning (PRT)

4. Variable Polygon Size PRT Path Planning (PRT-V)

5. Implementation & Future Works

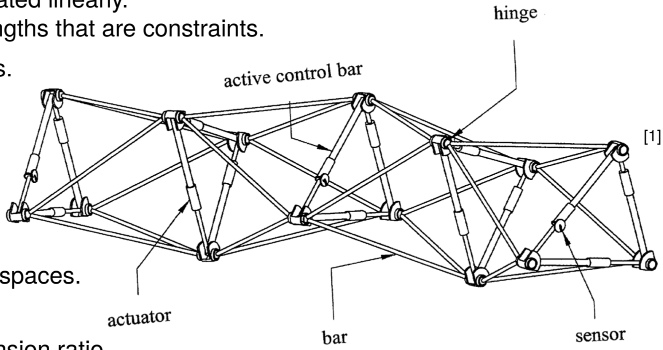
Outline

1. Variable Geometry Truss Robot (VGT)
2. Non-Impact Rolling Locomotion
3. Polygonal-RRT Path Planning (PRT)
4. Variable Polygon Size PRT Path Planning (PRT-V)
5. Implementation & Future Works

Variable Geometry Truss Topology

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

- **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.

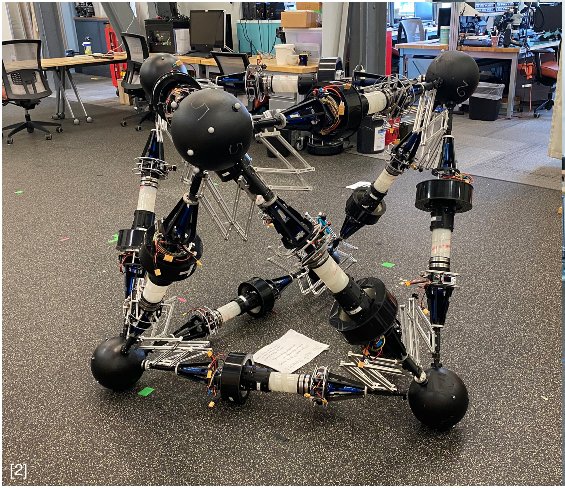


[1]

Advantages:
Variable size, pass-through confined spaces.

Disadvantages:
Needs a rigid actuator with high extension ratio.

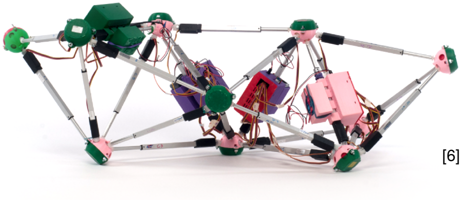
Realized Robots



Realized Robots

[4]

[5]



[6]

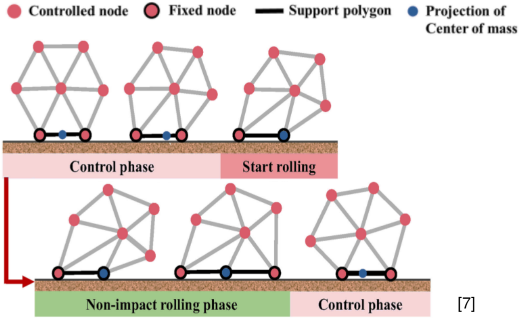
Outline

1. Variable Geometry Truss Robot (VGT)
2. Non-Impact Rolling Locomotion
3. Polygonal-RRT Path Planning (PRT)
4. Variable Polygon Size PRT Path Planning (PRT-V)
5. Implementation & Future Works

Locomotion for the Octahedron Structure

The locomotion objective is for the VGT's center of mass to follow the desired trajectory via rolling motion without ground impact hence it has no dynamic effects. The algorithm is optimization-based.

1. *Ground Contact:* Ground is a plane with,
   $p_{iz} \geq 0$
2. *Minimum and Maximum Edge Length:*
   $L_{min} \leq L_k \leq L_{max}$
3. *Minimum Angle Between Adjacent Edges:*
   $\theta_{i,j,k} = \cos^{-1}\left(\frac{(p_i - p_j)^T (p_i - p_k)}{\|p_i - p_j\| \|p_i - p_k\|}\right) \geq \theta_{min}$
4. *Collision Between Non-Adjacent Edges:*
   $d_{min}(e_k, e_l) \geq \mathrm{d}$
5. *Velocity of Member:* $\dot{L} = R\dot{x} \leq \dot{L}_{max}$

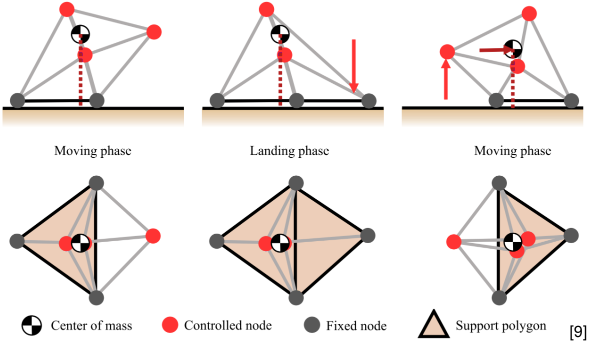


[7]

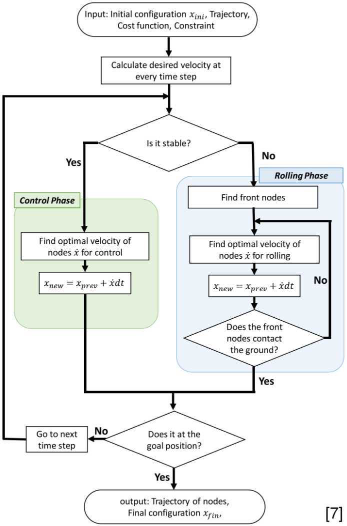
Locomotion for the Octahedron Structure

The velocity of nodes is optimized to move the center of mass given the desired velocity. The objective function is length of the members,[8]

$$\min \|J(\dot{x})\|^2 \text{ where } J(\dot{x}) = \|\dot{L}\|$$

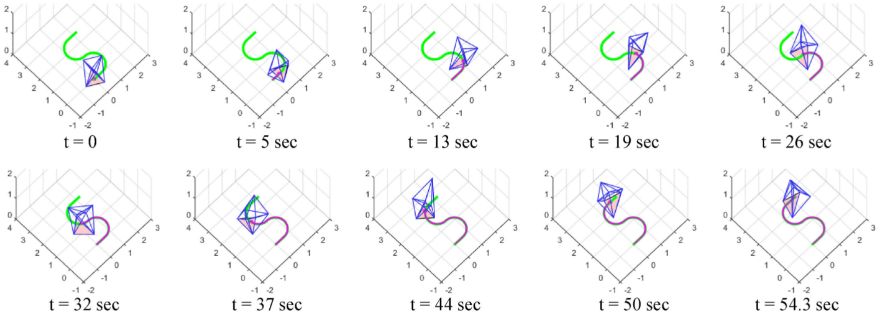


[9]



[7]

Locomotion for the Octahedron Structure



[7]

The path with "S" shape is tracked precisely with the center of mass projection, conforming the constraints.

Outline

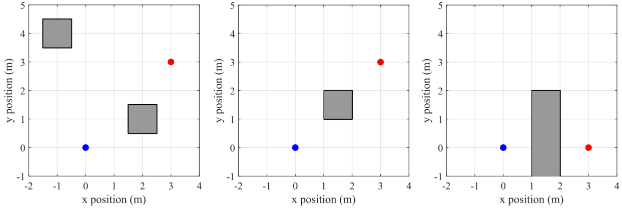
1. Variable Geometry Truss Robot (VGT)
2. Non-Impact Rolling Locomotion
3. Polygonal-RRT Path Planning (PRT)
4. Variable Polygon Size PRT Path Planning (PRT-V)
5. Implementation & Future Works

Polygonal-RRT Path Planning (PRT)

Having defined the truss structure and the locomotion algorithm, the path planning comes next. Start by describing the workspace.

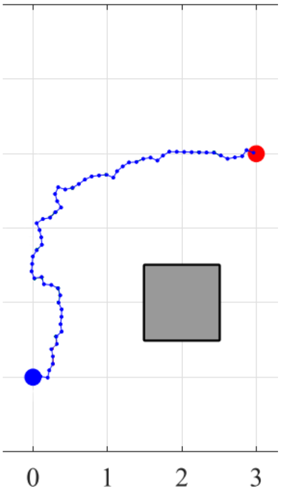
- 2D Plane
- Polygonal Obstacles
- Initial point and a goal point

Find a path for center of mass to follow



(a) (b) (c)

[9]

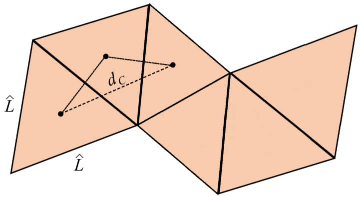


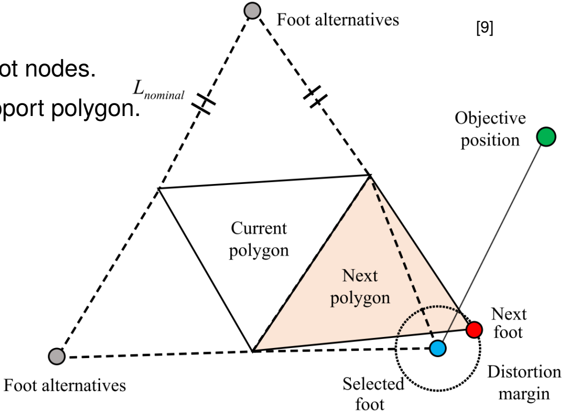
[9]

Polygonal-RRT Path Planning (PRT)

One can incorporate the geometry of the topology into the random tree search algorithm.

- Generate a tree that consist of polygons.
- Select the next branch from 3 possible foot nodes.
- Terminate when the goal is within the support polygon.

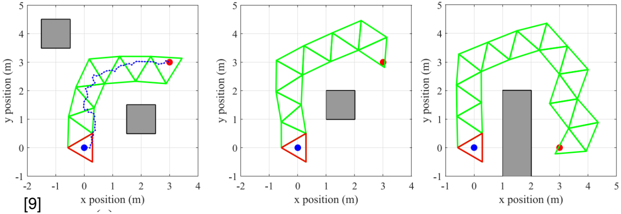




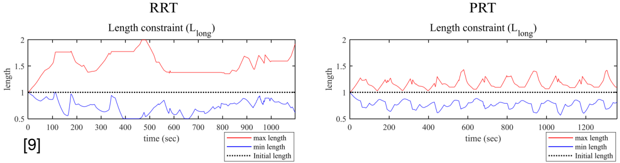
[9]

Polygonal-RRT Path Planning (PRT)

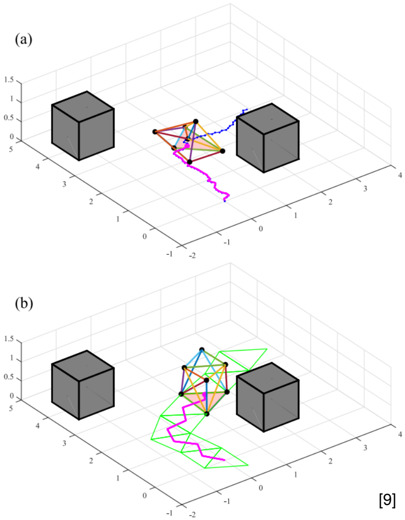
Comparative results differentiating the PRT and the RRT.



[9]



[9]

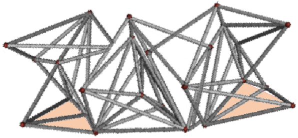


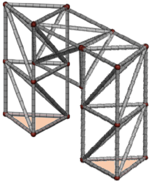
[9]

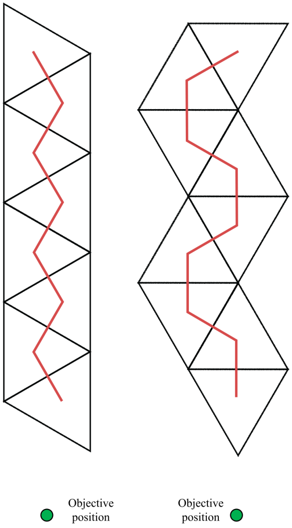
Discussions on PRT Results

Problems and ideas to be thought on.

- The selected tree branch size is too small for the RRT.
- Rotating around the CM mechanism can be added.
- A direction concept could be beneficial.
- CM trajectory can be smoothed.
- Why choose adjacent adjacent polygons as the support ?





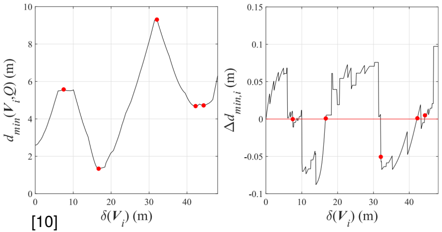


Outline

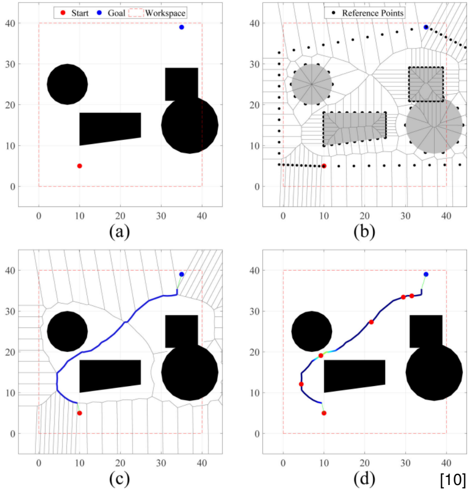
Variable Polygon Size PRT Algorithm

One of the advantages of the physical topology is the size changing aspect. The setting is still the same, but the question is when to change the size ?

1. Voronoi and Dijkstra's algorithm to find a path.
2. Classify the distance to the closest object.
3. Find **stepover** points that signal a size change.



[10]

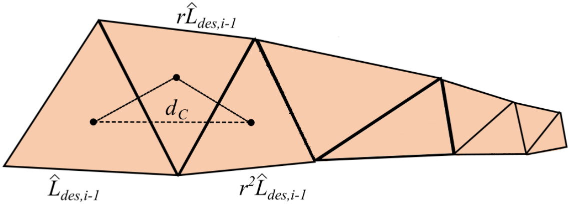


[10]

Variable Polygon Size PRT Algorithm

The variable size aspects builds upon the previous planning, modifying the algorithm slightly with added higher level steps such called prior planning.

- The stepover points are used as **waypoints**.
- Each waypoint has a nominal robot size ($\hat{L}_{des}$) associated.
- Plan for paths between consecutive waypoints and interpolate the size of the polygons inbetween.

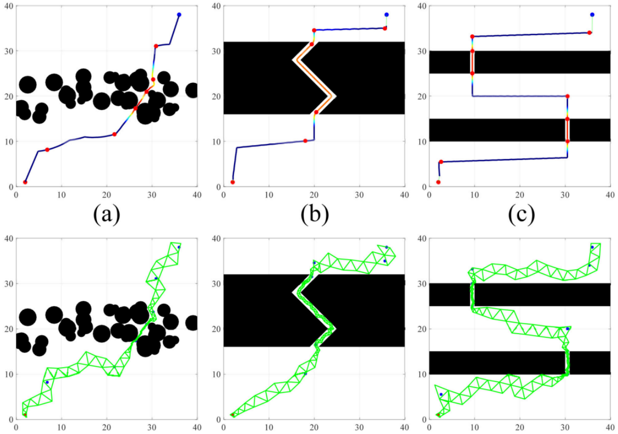


Algorithm 3: PolygonSearch.

Input: $Polygon_{init}$, S, $\hat{L}_{des}$
$T_1.init(Polygon_{init})$;
for $i = 1$ **to** $length(S)$ **do**
    $Goal\_Position = \boldsymbol{S}_i$;
    $Reach\_Goal = false$;
    while $Reach\_Goal == false$ **do**
        if $Random[0,1] \geq MixingFactor$ **then**
            $Obj\_Point = Random\_Position$;
        else
            $Obj\_Point = Goal\_Position$;
        end
        $FootAlts = \{\}$;
        for $Polygon\ in\ T_i$ **do**
            $\hat{L} = NextNominalLength(...$
            $Polygon, \boldsymbol{S}_i, \hat{L}_{des,i}, \hat{L}_{des,i-1})$;
            $FootAlts.Add(MakeFoots(...$
            $Polygon, \hat{L}, Obj)$;
        end
        $\boldsymbol{Foot}_{new} = FootAlts.ClosestTo(Obj\_Point)$;
        $Polygon_{new} = MakePolygon(\boldsymbol{Foot}_{new}, \hat{L})$;
        if $CollisionFree(Polygon_{new})$ **then**
            $T_i.AddPolygon(Polygon_{new})$;
            if $Goal\_Position \in Polygon_{new}$ **then**
                $Reach\_Goal = true$;
            end
        end
    end
    $T_{i+1}.init(Polygon_{new})$;
end
return T;

[10]

Simulation Results on PRT-V Algorithm



[10]

Discussions

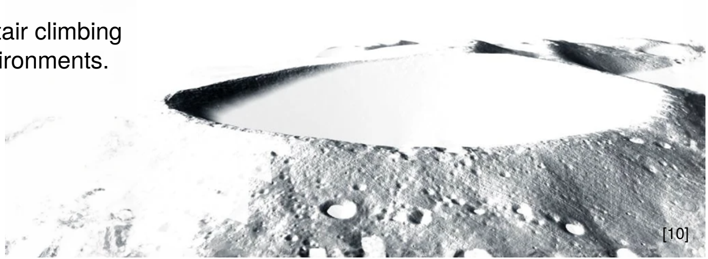
- Concerns on the minimum size of the robot passing through the path found from voronoi diagram
- Larger structure moves faster, however its easier to collide with the obstacles.
- Should the sampling density change when the search space become larger ?

Outline

1. Variable Geometry Truss Robot (VGT)
2. Non-Impact Rolling Locomotion
3. Polygonal-RRT Path Planning (PRT)
4. Variable Polygon Size PRT Path Planning (PRT-V)
5. Implementation & Future Works

Implementation & Future Works

- The implementation will be conducted using MATLAB™, with dynamic simulation and visualizations performed in Rhino/Grasshopper®.
- Evaluate and document the generalizability of the pipeline for robots with various topologies.
- Modify locomotion and path planning strategies to accommodate irregular non-planar terrains.
- Develop an approach for stair climbing and navigation in 2.5D environments.



[10]

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] 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.

[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, 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.

[10] J. Bae, S. Park, M. Yim, and T. Seo, “Polygon-based random tree search algorithm for a size-changing robot,” *IEEE Robotics and Automation Letters*, vol. 7, no. 3, pp. 8100–8105, 2022.

Thank you for listening