Design of Track-Based Climbing Robots Using Dry Adhesives

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Introduction

Dry adhesives are an ideal source of adhesion for climbing mobile robots. One commercially available dry adhesive is known as micro suction tape. This adhesive is low cost, durable, and easily procurable.

While track-based climbing mobile robots have been more extensively studied when using magnetic adhesion, dry adhesives are another option that have unique properties that require consideration during design. One such property is the necessity of a "preload" where the maximum adhesion of a track element is heavily dependent on the force with which it is applied to the surface.

The objective of this poster is to show a method of modelling track-based mobile robots utilizing this dry adhesive and demonstrate the model's use in a specific robot design.

Climbing Robot Suspensions

Due to the flexible nature of tracks, track-based climbing robots require a suspension to avoid the concentration of the force on the highest track element. Figure 1 shows a climbing robot suspension as it artificially "pulls" on the surface to maintain equilibrium.

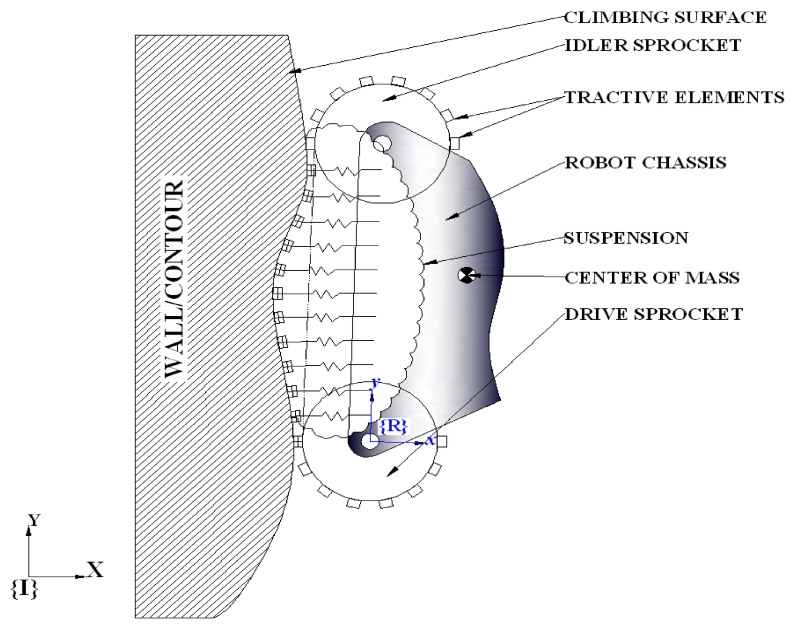

Figure 1: Climbing Robot Suspension [1]

Robot Model

The robot is modelled as consisting of 4 constant pressure regions with pressure w_n, length l_n, and width b.

- **Region 1:** Preload Adhesive – w_1
- **Region 2:** Suspension Loads Adhesive – w_2
- **Region 3:** Resultant Compressive Region – w_3
- **Region 4:** Adhesive Removal – w_4

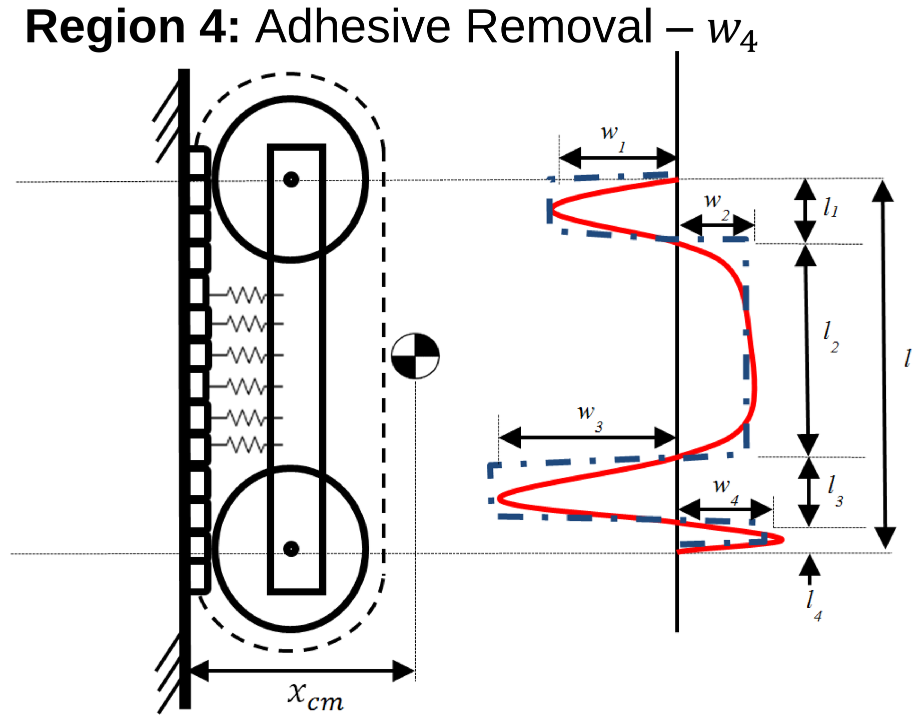

Figure 2: Robot Model with Force Profile

Climbing Equilibrium Equations

Considering that two static equilibrium equations are available, two further constraint equations are needed to solve for the track pressures.

Equation 1: Suspension Tuning Parameter

Since the suspension tension can be tuned based on the maximum adhesion pressure of the tractive element, w_4 can be scaled by a factor of safety to yield w_2.

Equation 2: Adhesive Model

For the dry adhesive considered, the maximum adhesion pressure, w_4, has been found to be a nonlinear function of the preload pressure, w_1 [2]. Therefore, the system of linear equations below was iteratively solved with the adhesion equations to result in a set of pressures for a given robot configuration.

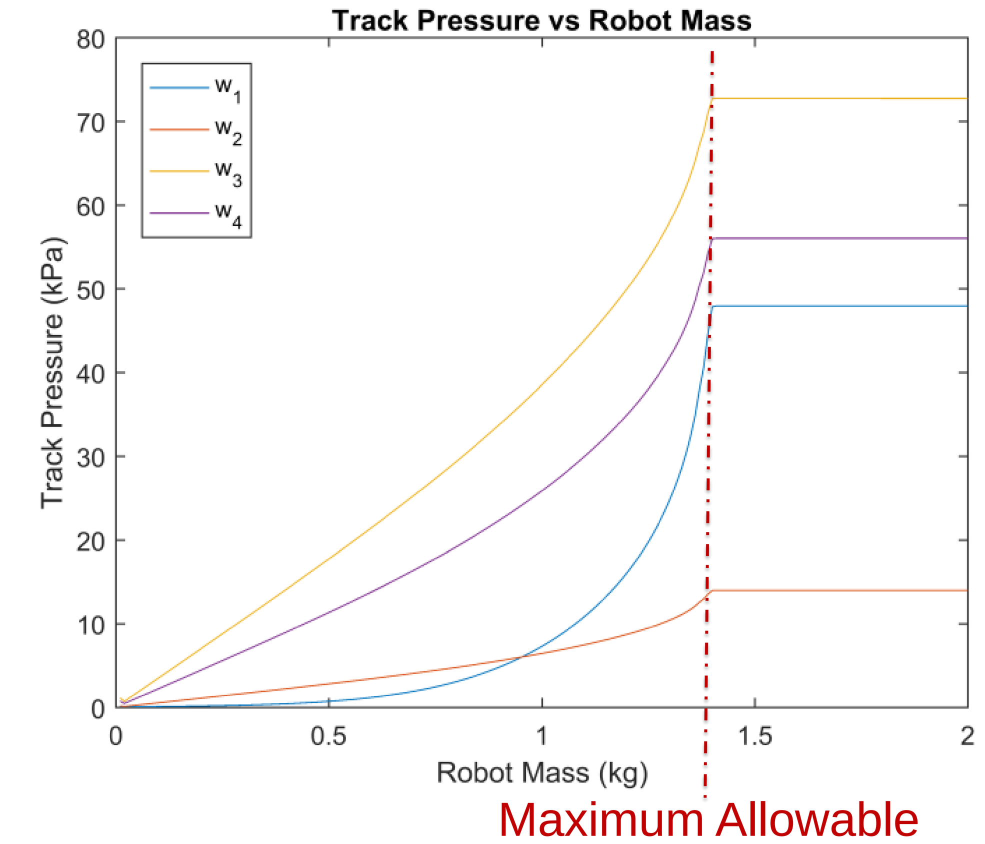

Figure 3: Track Pressures for Varying Robot Mass, m

$$b * \begin{bmatrix} -l_1 & l_2 & -l_3 \\ -l_1\left(\frac{l_1}{2}+l_2+l_3+l_4\right) & l_2\left(\frac{l_2}{2}+l_3+l_4\right) & -l_3\left(\frac{l_3}{2}+l_4\right) \\ 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} w_1 \\ w_2 \\ w_3 \end{bmatrix} = b * \begin{bmatrix} -l_4 w_4 \\ -l_4\left(\frac{l_4}{2}\right) * w_4 + \frac{mgx_{cm}}{b} \\ \frac{w_4}{FoS} \end{bmatrix}$$

Suspension Design

By detecting the point shown in Figure 3 at which the robot is no longer able to remain on the surface, the effects of varying robot parameters can be studied. Since the robot model is scalable with a length, a dimensionless ratio, r_n can be considered such that

$$l_n = l * r_n$$

Application Specific Considerations

1) Discrete track elements have a finite length.

→ r_1 and r_4 can be controlled by resizing the track element relative to the overall length, and $r_1 = r_4$.

2) This dry adhesive performs best within a range of preload pressures (shown as dotted lines in Figure 4).

→ Suspension length, r_2, should be scaled such that the preload pressure is in the center of the desirable region.

The effects of changing pressure region lengths can be evaluated for a given factor of safety as shown in Figure 4 to find a desirable preload pressure.

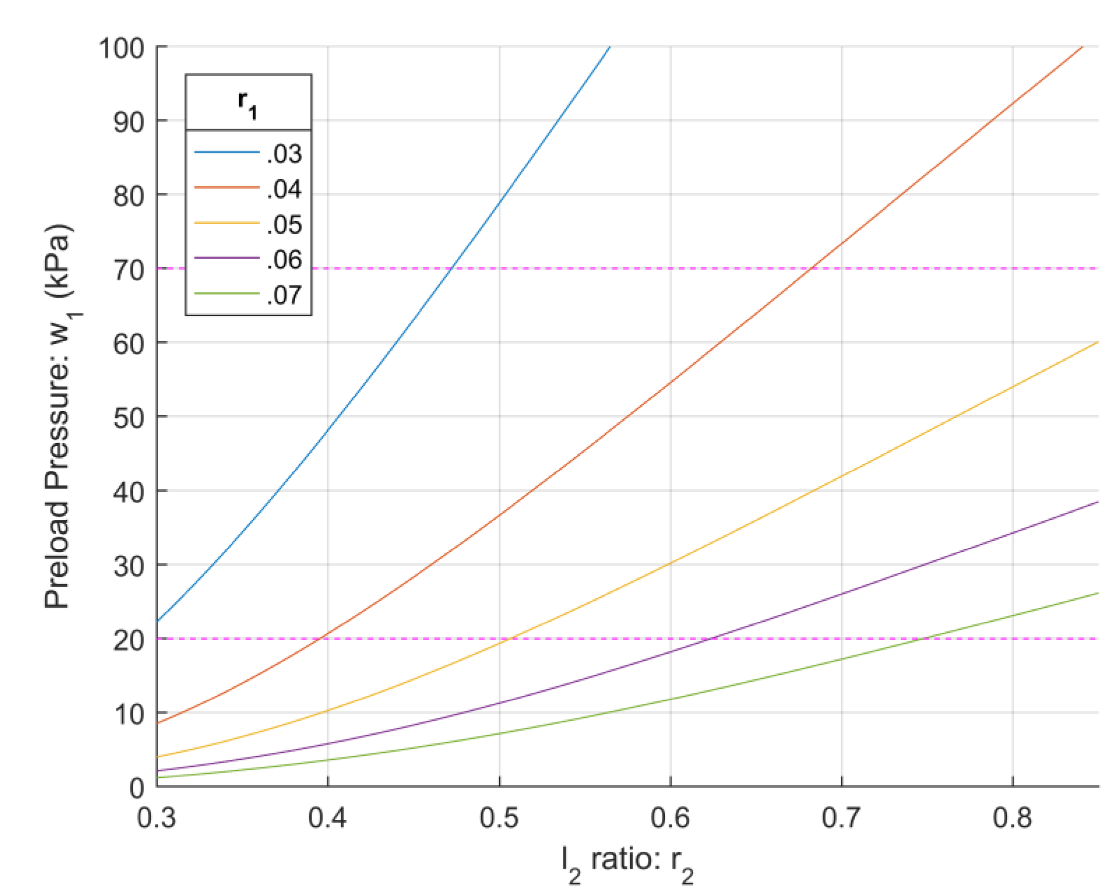

Figure 4: Adhesive Preload Pressure for Varying Suspension Length Ratios

Usage Example

Design Requirements

- Payload (m) = 1kg
- Track Length (l) = 15cm
- Track Width (b) = 2cm
- Center of Mass Location (x_{cm}) = 8cm

Design Process

1. Factor of safety is chosen to be 2.
2. r_1 and r_4 are chosen to be 0.05.
3. Selecting a point within the preferred preload region, r_2 is chosen to be 0.70.
4. r_3 is calculated, and the robot is fabricated.

Prototype Robot

Prototype robots have been developed and tested using the model shown. They demonstrate the behavior expected based on the robot model and have successfully demonstrated the ability to place and preload new tractive elements in the course of a climbing cycle. The robot from the example below is pictured in Figure 5.

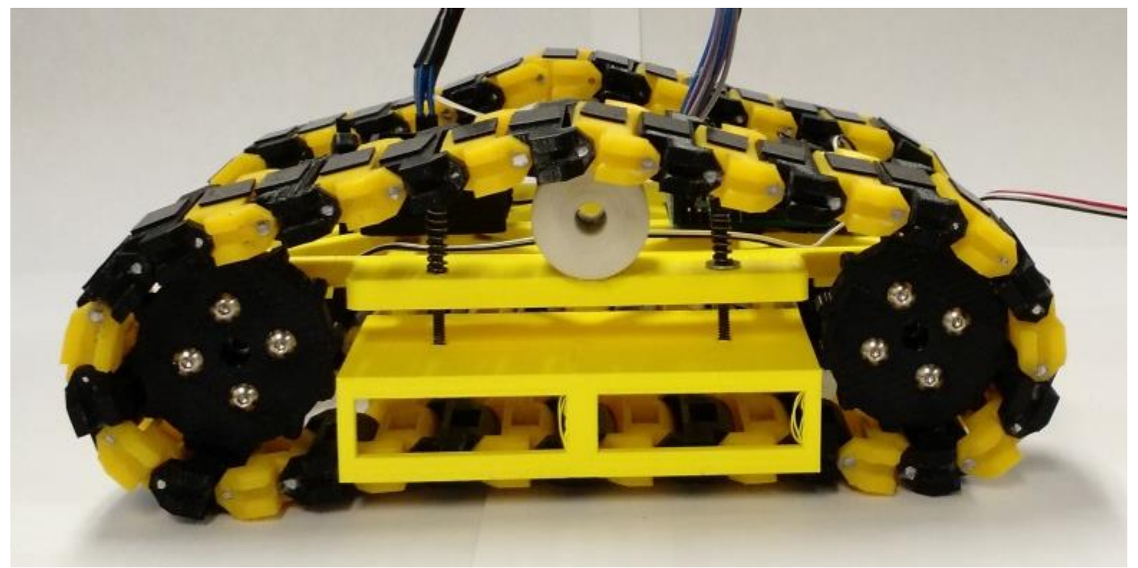

Figure 5: Mobile Robot with Suspension Designed for Suction Cup Tape Dry Adhesive

Conclusions

Dry adhesives are viable for track-based climbing mobile robots. Further, the proposed model is able to accurately predict the necessary bulk characteristics of the suspension and track elements for a given set of design constraints. However, more work is needed to improve the details suspension design and eliminate abnormalities due to geometric tolerances and other physical abnormalities.

Future Work

- Explore fibrillar dry adhesives and other experimental adhesive options
- Develop compact and lightweight suspension that allows for tuning springs in a nonlinear fashion
- Modify models for climbing in non-vertical poses

References

[1] P. Kumar, T. W. Hill, D. A. Bryant and S. L. Canfield, "Modeling and Design of a Linkage-Based Suspension for Tracked-Type Climbing Mobile Robotic Systems," *ASME 2011 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference,* pp. 827-834, 2011.

[2] M. W. Powelson and S. L. Canfield, "Design if Track-Based Climbing Robots Using Dry Adhesives," *ASME 2017 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference, [in review].*

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