Spiderbot V2 Mechanical Calculations

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Abstract

This is a documentation of all the calculations performed for SpiderBot V2. These calculations were used to determine the spring coefficient, spring coil thickness, number of turns, required motor torque. The method of Free-Body Diagram (FBD) and Gauss elimination was used to determine the reaction forces on each link subject to external forces. These forces can also be used to further perform stress analysis for designing the links of the robot.

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1 Introduction

SpiderBot V1 suffered from significant drawbacks such as low operational time, burning motors, and no space for accommodation of high level sensors like stereo camera, LIDAR and even sufficient battery backup. Optimization of these parameters was the main motive behind designing the SpiderBot V2.

Spiderbot V2 makes use of a parallel four-bar linkage mechanism to reduce 1 motor per leg by having the end link always being perpendicular to the ground. This setup will only limit the robot in extreme environments and hence very specific cases and in general, is an improvement over V1. Introduction of spring between two parallel linkages is made in order to balance out the weight of the robot when it is standing. This enables the robot to completely switch off all the motors when standing and can switch off half of the motors when moving, thus saving a lot of power.

2 FBD calculations and equations for determination of spring coefficient

2.1 Variables

The robot has been divided into 4 Free Bodies. Link1, Link2 and Link3 of a leg and the remaining Body abbreviated as L1, L2, L3, B. The variables are therefore named as follows and are also shown in the diagram below.

N_{VL1B} : Vertical reaction force between L1 and B

N_{HL1B} : Horizontal reaction force between L1 and B

N_{VL1L3} : Vertical reaction force between L1 and L3

N_{HL1L3} : Horizontal reaction force between L1 and L3

N_{VL2B} : Vertical reaction force between L2 and B

N_{HL2B} : Horizontal reaction force between L2 and B

N_{VL2L3} : Vertical reaction force between L2 and L3

N_{HL2L3} : Horizontal reaction force between L2 and L3

f_s : Force exerted by the spring

F : Frictional force between L3 and ground OR legs and ground

2.2 Known quantities

The known quantities are mentioned below.

m_1 : Mass of L1 = 0.060767 kg (60.767 g)

m_2 : Mass of L2 = 0.0125 kg (12.5 g)

m_3 : Mass of L3 = 0.012443 kg (12.443 g)

m_{hb} : Mass of the hexagon center part of B = 2.59 kg

g : Acceleration due to gravity = 9.81 m/s^2

l_{L1} : Length of L1 = 0.146293 m (146.293 mm)

l_{L3} : Length of L3 = 0.15834 m (158.34 mm)

l_{CL1} : Distance of COM of L1 from pivot = 0.07315 m (73.15 mm)

l_{CL2} : Distance of COM of L2 from pivot = 0.07315 m (73.15 mm)

l_{CL3} : Distance of COM of L3 from top pivot = 0.07315 m (73.15 mm)

θ : Angle between L1 and horizontal = $\frac{\pi}{18}$ radians (10°)

ϕ : Angle between Spring and vertical = $\frac{63.93437\pi}{180}$ radians (63.93437°)

l_V : Vertical separation between L1 and L2 = 0.05 m (50 mm)

l_S : Distance between link pivot and spring pivot = 0.035 m (30 mm)

N : Normal reaction between legs and ground

2.3 Equations

Clockwise positive, positive Y-axis as positive and positive X-axis as positive is the sign convention used to formulate the equations.

$$N = \frac{m_{hb} + 6(m_1 + m_2 + m_3)}{6}$$

Force equilibrium in X-direction on L1:

$$-N_{HL1B} + f_s \sin\phi + N_{HLIL3} = 0 \tag{1}$$

Force equilibrium in Y-direction on L1:

$$N_{VL1L3} - N_{VL1B} - f_s \cos\phi = m_1 g \tag{2}$$

Torque equilibrium (About A) on L1:

$$f_s l_S(\cos\phi\cos\theta + \sin\phi\sin\theta) + N_{HL1L3} l_{L1} \sin\theta - N_{VL1L3} l_{L1} \cos\theta = m_1 g l_{CL1} \cos\theta \tag{3}$$

Force equilibrium in X-direction on L2:

$$N_{HL2L3} - N_{HL2B} - f_s \sin\phi = 0 \tag{4}$$

Force equilibrium in Y-direction on L2:

$$N_{VL2L3} + f_s \cos\phi - N_{VL2B} = m_2 g \tag{5}$$

Torque equilibrium (About B) on L2:

$$N_{HL2L3} l_{L1} \sin\theta - f_s (l_{L1} - l_S)(\sin\phi \sin\theta + \cos\phi \cos\theta) - N_{VL2L3} l_{L1} \cos\theta = -m_2 g l_{CL2} \cos\theta \tag{6}$$

Force equilibrium in X-direction on L3:

$$-N_{HL1L3} - N_{HL2L3} - F = 0 \tag{7}$$

Force equilibrium in Y-direction on L3:

$$-N_{VL1L3} - N_{VL2L3} = m_3 g - N \tag{8}$$

Torque equilibrium (About E) on L3:

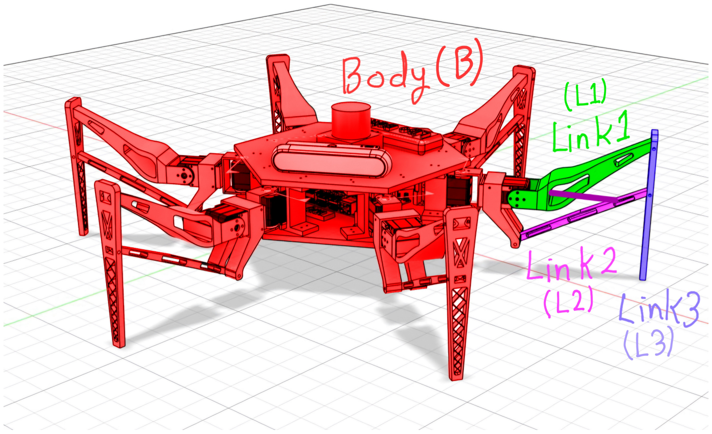
$$-N_{HL1L3} l_{L3} - N_{HL2L3}(l_{L3} - l_V) = 0 \tag{9}$$

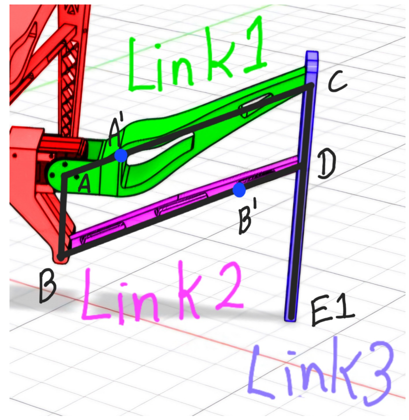
Torque equilibrium (About B) on B [in the plane of the linkage under consideration]:

$$\begin{aligned} N_{HL1B} l_V - 0.10834F = {} & 2 \times 0.02204N - 2 \times 0.22204N - 0.34407N \\ & + 2 \times 0.18602(m_1 + m_2)g + 2 \times 0.01398(m_1 + m_2)g + 0.27204(m_1 + m_2)g \\ & + 2 \times 0.22204 m_3 g + 0.34407 m_3 g - 2 \times 0.02204 m_3 g + 0.1 m_{hb} g \end{aligned} \tag{10}$$

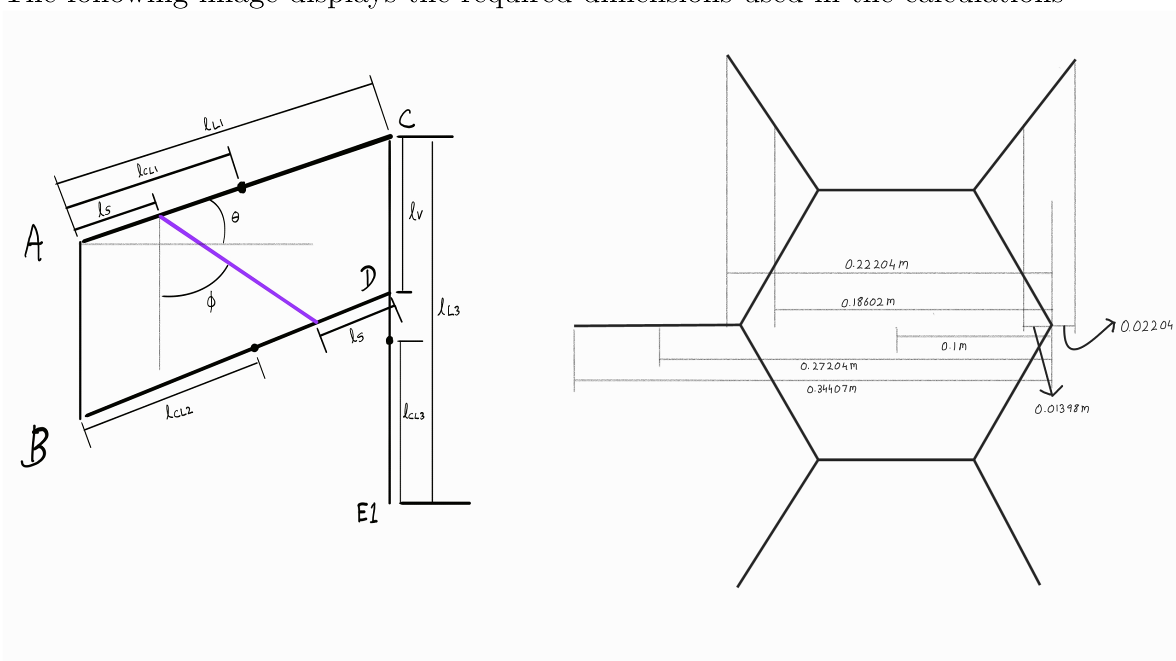
2.4 Images

The following images showcase the distinction of the Free-Body Diagrams made and the visualization for the kinematic link adopted for simplification of calculations. The purple line between L1 and L2 represents the spring that was not modeled at the time of the CAD model.





The following image displays the required dimensions used in the calculations



The following image is the FBD linkage diagram, based on which the equations have been formulated. The forces " F' " in the FBD of B is a component of F in the plane of the linkage under consideration. Since these forces cancel each other out and have no effect in Eq. (10), their values has not been calculated. The diagrams represent the front-view of the linkage/robot based on the main FBD distinction image.