

A Consideration of Inflatable Circles

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1 Introduction

This is a study of the basic math of inflatable spheres as a tool for soft robotics. We begin with a study in two dimension to simplify the problem. Our final goal is to analyze three dimensional soft robots composed of inflatable spheres.

2 Problem I: Circles in Fixed Postions

A very simplified version of the problem is to imagine that a two-dimensional plane. Instead of spheres, we will assume we have circles of changable radius. This is in fact realistic of a soft robot constrained to a plane.

Eventually we hope to have circles pressing against each other, or tangent or “kissing”. However, the problem is a bit simpler if we assume we have two circles, each of which is constrained to have its center on the a vertical line (see Figure 1.) We place the circle C_1 with radius r_1 on the $x = -1$ line, and assume that it rests on a shelf or plane on the x -axis. Assume the C_2 circle whose radius if r_2 is on the $x = 1$ line.

Let A the intersection of the tangent line supported by the inflatable circles with the x -axis. Call the distance of A on the x -axis x . Let ψ be the angle formed by the circle centers with the x axis (measured counterclockwise).

If the radii are less than 1 so that no issues of intersection of the circles arise, we have:

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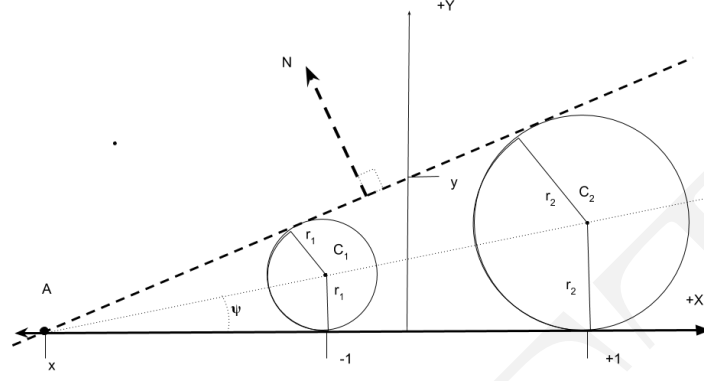


Figure 1: Problem I: Fixed Circles Centers

$$\tan \psi = \frac{r_1}{x-1} = \frac{r_2}{x+1} \quad (1)$$

$$r_2(x-1) = r_1(x+1) \quad (2)$$

$$r_2x - r_2 = r_1x + r_1 \quad (3)$$

$$r_2x - r_1x = r_1 + r_2 \quad (4)$$

$$x(r_2 - r_1) = r_1 + r_2 \quad (5)$$

$$x = \frac{r_1 + r_2}{r_2 - r_1} \quad (6)$$

$$\tan \psi = \frac{r_1}{x-1} \quad (7)$$

$$\psi = \arctan \frac{r_1}{x-1} \quad (8)$$

$$N = \begin{bmatrix} -\sin \psi \\ \cos \psi \end{bmatrix} \quad (9)$$

$$(10)$$

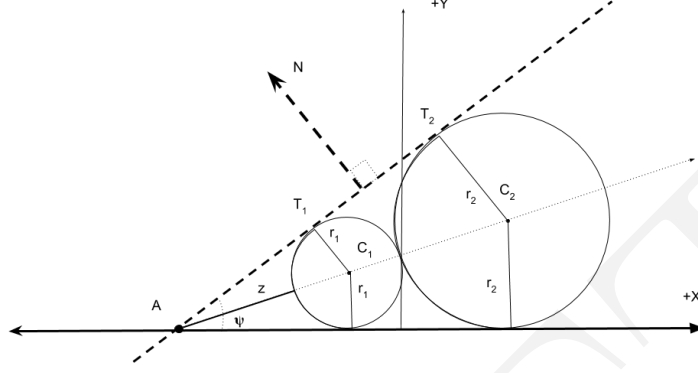


Figure 2: Problem II: Tangent Circles

3 Problem II: Tangent Circles

$$\frac{r_2}{\|C_2 - A\|} = \frac{r_1}{\|C_1 - A\|} \quad (11)$$

$$\|C_2 - A\| = r_2 + 2r_1 + z \quad (12)$$

$$\|C_1 - A\| = r_1 + z \quad (13)$$

$$\frac{r_2}{r_2 + 2r_1 + z} = \frac{r_1}{r_1 + z} \quad (14)$$

$$z = -\frac{2r_1^2}{r_1 - r_2} \text{ and } r_1 \neq r_2 \text{ and } r_1 r_2 (r_1 + r_2) \neq 0 \quad (15)$$

$$\sin \psi = \frac{r_1}{z + r_1} \quad (16)$$

$$\theta = \frac{2 \arcsin r_1}{z + r_1} \quad (17)$$

$$Nx = -\sin \pi/2 + \theta \quad (18)$$

$$Ny = -\cos \pi/2 + \theta \quad (19)$$

$$(20)$$