Auto-calibration and Hybrid Force/Position Control for the Cerberus Cardiac Robot

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Background

Cerberus
- Planar parallel wire robot for minimally invasive heart surgery
- Adheres to beating heart via suction on three bases
- Rapidly preform multiple injections for gene therapy research

Problems
- Actuation redundancy
- Wires can only pull, not push
- Coupled, nonlinear state equations
- Unknown deployed geometry

Goal
- Add force control to existing position control to maintain wire tension and increase position accuracy to make device safer for surgery
- Auto-calibration

Auto-calibration

- Kinematics and statics depend on accurate knowledge of geometry
  - Geometry is unknown after deployment onto heart

- **Auto-calibration**
  1. Start in any configuration
  2. Uses forces to move to each base
  3. Estimates geometry using encoder values
  4. Updates to current geometry

Algorithm

Data: Wire tensions and encoder values
Result: Geometry of robot for each base

```
while target base wire < T_max
  pull target base wire and keep other wire = T_max
end
```

- Record encoder values
- Convert encoder values to lengths
- Use law of cosine to find angles

Hardware

Load cells with pulleys measure tension
Pulleys

Pixy Camera measures locations via color tracking

Kinematics and Statics

Inverse Kinematics [1]

- Wire lengths
  \[
  \begin{align*}
  r_1^2 &= (x_0 + L_1 \cos \theta_1)^2 + (y_0 - L_1 \sin \theta_1)^2 + y_0^2
  
  r_2 &= (x_0 - L_\tau \cos \theta_2)^2 + (y_0 - L_\tau \sin \theta_2)^2
  
  \end{align*}
  \]

Optimal Tension Distribution [2, 3]

- Maximize workspace
- \( T_{\min} \leq f \leq T_{\max} \)
  - Break wires or restrict heart movement
  - \( f \ll T_{\min} \) → Lose control of wire

\[
\alpha = \frac{T_{\min}}{N_{\min}}
\]
\[
N = \frac{r_1}{r_2} = \frac{\sin \varphi_r}{\sin \varphi_r - \sin \varphi_t}
\]

Future work

- Improve geometric assumptions
- Translate algorithm to curved surface for more realistic heart conditions

References