A Gazebo Simulator for Continuum Parallel Robots

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- Serial robots
  - Simpler and more used
  - Limited by precision and inertia
- Parallel robots
  - Less inertia, high velocities
  - More joints involved

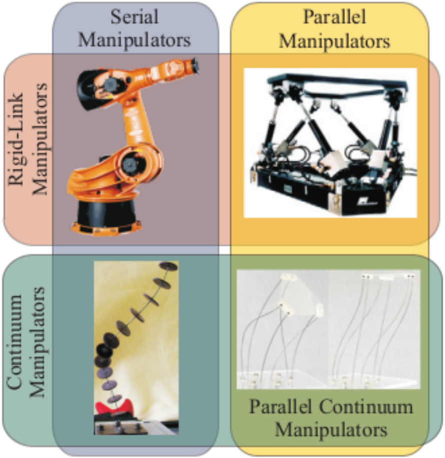

Figure: Different robot architectures

Continuum parallel robots

- Continuum parallel robots
  - May anhance safety
  - Cheaper components
  - Possible to miniturize
- Model and stability problems
  - More unstable configurations
  - Another drawback
  - Not analytical solution

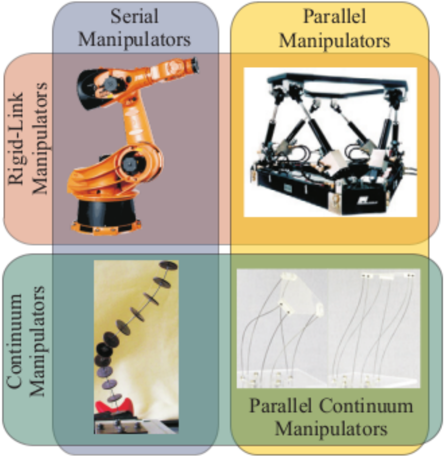

Figure: Different robot architectures.

CPR simulator

- General simulator
  - Gazebo
  - Different robots
- Solve the modelling
  - Rod statics
  - Robot assembly
  - Visual interface
  - Robot dynamics
- Modelling of continuum

- Rod as 1D body
- Function of the arc-lenght s
    - Centerline position $p_{(s)} \in \mathbb{R}^3$
    - Cross-section orientation $R_{(s)} \in se(3)$
- Define transformation

$$T_{(s)} = \begin{bmatrix} R_{(s)} & p_{(s)} \\ 0 & 1 \end{bmatrix} \in SE(3) \quad (1)$$

- Derivative wrt arc-lenght $x' = \frac{\mathrm{d}x}{\mathrm{d}s}$

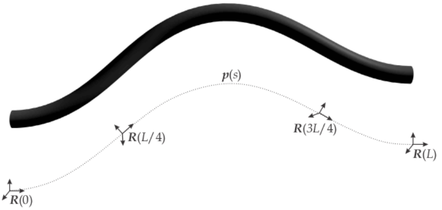

Figure: Rod geometric modelling

Equilibrium Equations

- Equilibrium consideration
  - Distributed forces/moments
  - Internal forces/moments

$$n'_{(s)} = -f_{(s)} \tag{2}$$

$$m'_{(s)} = -p'_{(s)} n_{(s)} - l_{(s)} \tag{3}$$

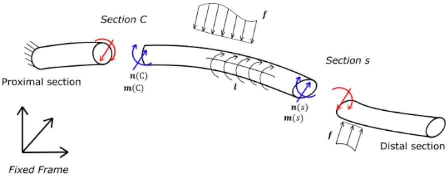

Figure: Sections of the beam considered for the static equilibrium.

Boundary Value Problem

- Constraints at the distal plate
  - External wrench $\Psi_{ext} = \begin{bmatrix} F \\ M \end{bmatrix}$
  - Rod contribution $\Psi_i = \begin{bmatrix} n_{i(L_i)} \\ m_{i(L_i)} \end{bmatrix}$
- Constraints at the base
  - Actuations Ψ_{a_i}
  - Joints and geometry

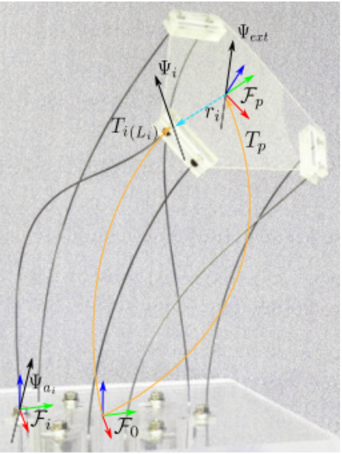

Figure: Geometrical and actuation constraints for a Stewart-Gough CPR.

Shooting Method in statics (Stewart-Gough CPR)

- ODE system in statics
- Recursive solution
  - Needs an intial guess
  - Evaluation on a cost function

$$\boldsymbol{f} = \begin{bmatrix} \sum n_{i(L_i)} - F \\ \sum \left[p_{i(L_i)} n_{i(L_i)} + m_{i(L_i)} \right] - p_d F - M \\ p_d + R_d r_i - p_{i(L_i)} \\ \left[R_i^T{}_{(L_i)} R_d - R_{i(L_i)} R_d^T \right]^V \end{bmatrix} \tag{4}$$

- Sensitive to initial conditions

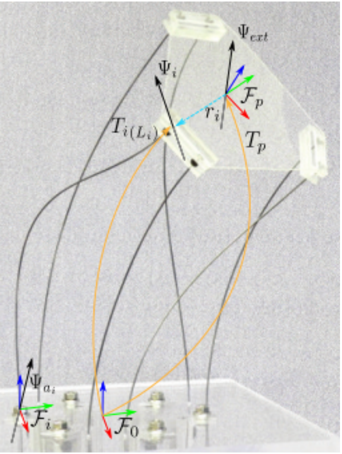

Figure: Geometrical and actuation constraints for a Stewart-Gough CPR.

Shooting Method in dynamics

- PDE system
  - Derivative wrt to arc-lenght $x^{'} = \frac{\partial x}{\partial s}$
  - Derivative wrt to time $\dot{x} = \frac{\partial x}{\partial t}$
- From PDE to ODE
  - Implicit discretization

$$\frac{\partial x}{\partial t} = c_0 x^{(i)} + \sum_{k=1}^{\infty} \left[c_k x^{(i-k)} + d_k \dot{x}^{(i-k)} \right] \tag{5}$$

$$\frac{\partial x}{\partial t} = c_0 x^{(i)} + c_1^{(i-1)} x^{(i-1)} + c_2^{(i-2)} x^{(i-2)} + d_1^{(i-1)} \frac{\partial x^{(i-1)}}{\partial t} \tag{6}$$

- Non linear solver

Strain approach, modelling

- Modelling of a continuum body in space
  - With its configuration space $C = SE(3) \times S$
- From assumption on rod deformation
  -
  - Allowed twist ξ_a
  - Prohibited twist ξ_c
- Discretization of the vector field

Strain approach, solution

- Strain Approach
  - Details here

Introduction to the Isogeometric Collocation Method

- NURBS curves represent vector field
    - Control point as degree of freedom
    - Basis functions relate influence
- Cost function
    - Equilibrium equation evaluated at collocation points

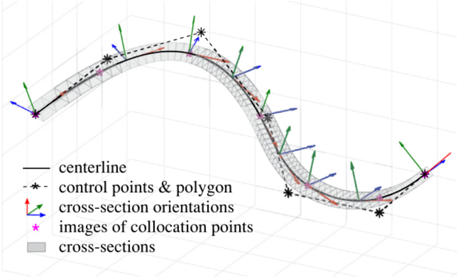

Figure: Rod centerline position and orientation represented with NURBS curves

Properties of the Isogeometric Collocation Method

- Less integrations
  - In statics no integration
  - ODE in dynamics
- Introduces possibility of modelling
  - Contact between rods
  - Changes in shape and or material
  - Rods coupling

- TODO
  - TODO

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