Kinematic Modeling of Cable Wrapping in Complex Geometrical Shaped Cable-Driven Parallel Robots

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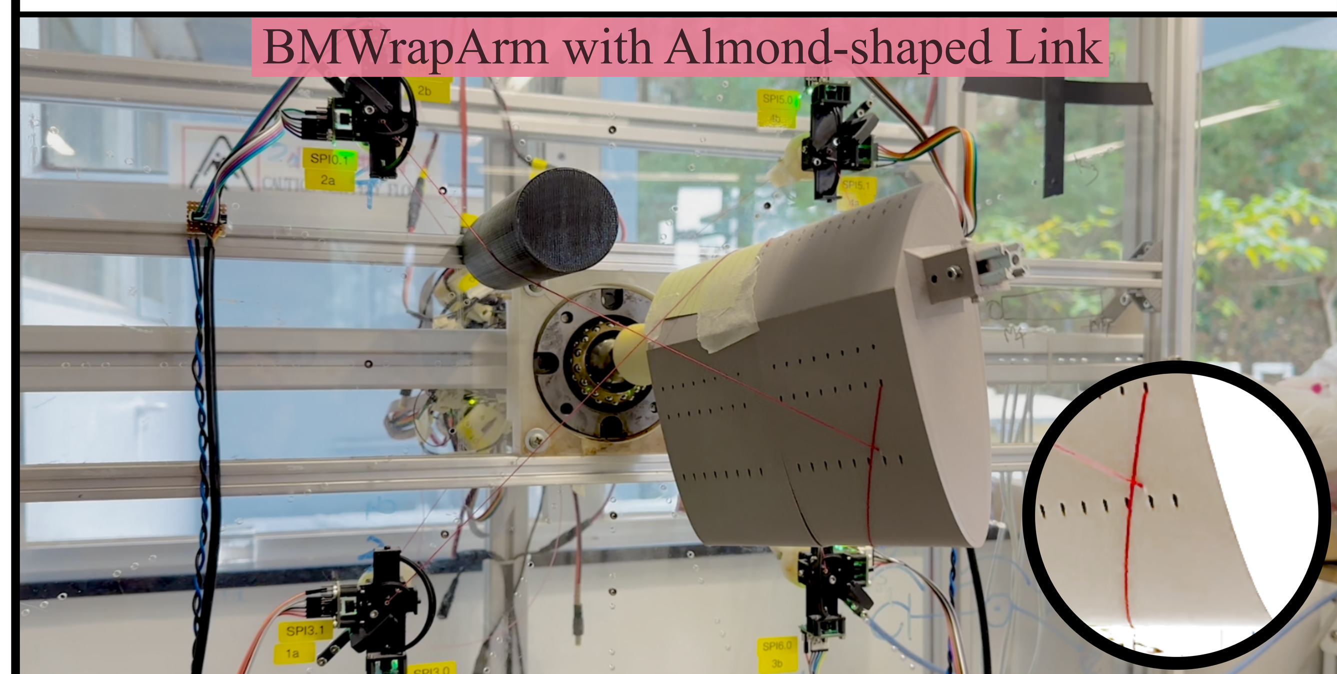
Cable Driven Parallel Robots (CDPR)s are a type of parallel manipulator where cables actuate the movement of rigid body links. In CDPR kinematic modeling, if interferences between cable andits nearby convex-shaped surfaces, such as links and obstacles, are permitted, then the cable starts to wrap around the surface once it collides with them; the phenomenon is known as cable wrapping. The primary goal of this work is to numerically obtain the cable wrapping model for CDPRs with complex-shaped links and obstacles, to enhance the CDPR performance.

Introduction



CDPR — Type of parallel manipulator where cables actuate the movement of rigid body links

- Low inertia.
- Large ential workspace
- High reconfigurability and transportability
- Cable-link interference
- Cable-obstacle interference

CDPR ***Key Performance Metrics (KPMs)***

KPMs:
- Accessible workspace
- Trajectory planning
- Obstacle handling
- Confined-space navigation

PREVIOUS RESEARCH LIMITATION — In CDPR kinematic modeling, previous works have focussed on handling interferences by avoiding them.

GOAL — Permitting the interferences by modelling cable wrapping on complex CDPR rigid bodies.

- Enhanced KPMs
- Effifcient musculoskeletal robot design
- Larger moments
- Higher rotational workspace

Research

CONTRIBUTIONS

- Novel ***Cable Wrapping Inverse Kinematics (CWIK)*** model for CDPRs to solve cable wrapping in any complex-shaped CDPR links or obstacles has been proposed.
- The CWIK model was used to solve the ***Cable Wrapping Forward Kinematics (CWFK)*** problem.
- Simulations and experiments were performed to show the generic nature of the framework.

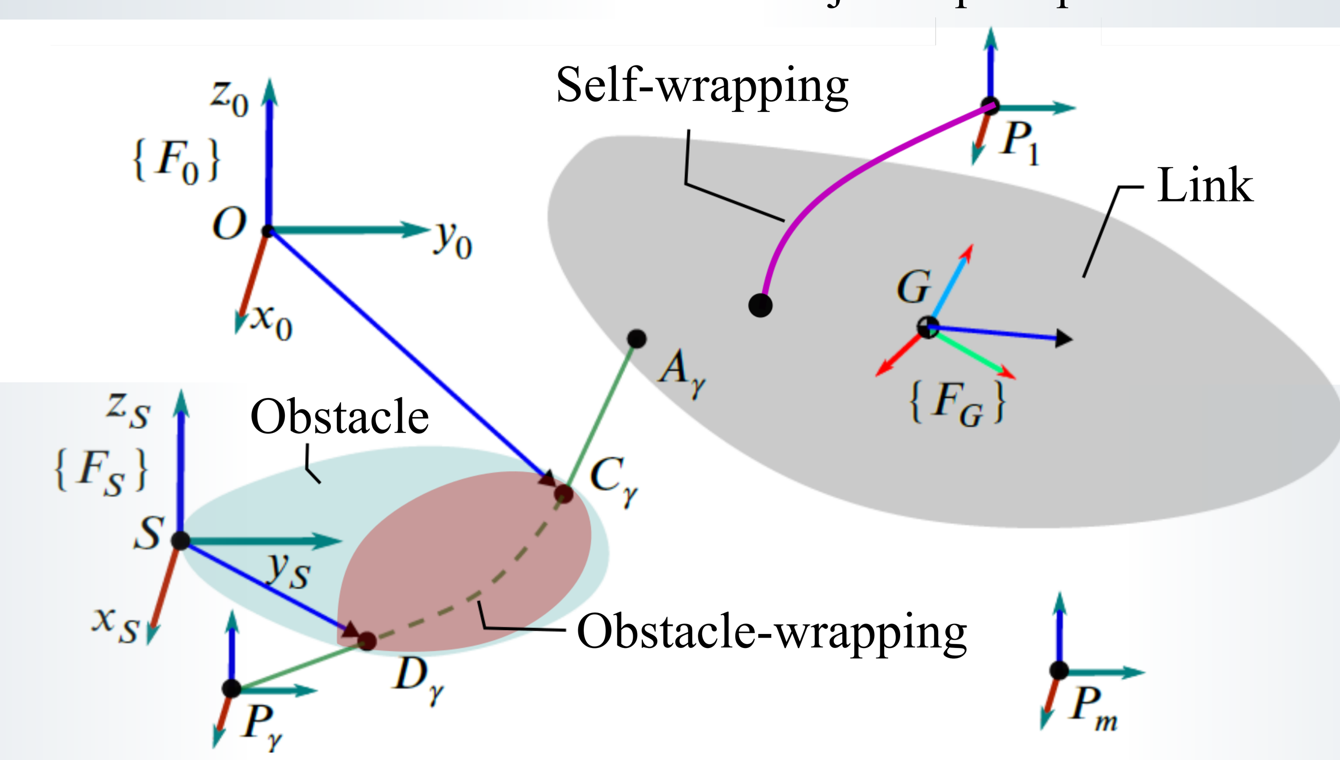
METHODOLOGY

1 Cable Wrapping Geodesics (CWG):
CWGs are shortest length curves that never move sideways, denoted by $\boldsymbol{\alpha}(\tau) \in \mathbb{R}^3$, τ is arc-length parameter

Objective
Determine curve ACDP such that
1. arc CD is CWG.
2. ACDP is smooth and continuous.

2 Assumption:
1. All CDPR cables are taut.
2. Parametric equations of the links and the obstacles are known.
3. Point A and P are known.

CWG Problem:
Point C and D are unknown and varies with CDPR joint-space position.



3 CWG Tangent at point C and D
Tangents at C and D are
If curve AP is smooth and continuous,

$$g_C(\tau_C) = \hat{\boldsymbol{T}}(\tau_C) \cdot \hat{\boldsymbol{r}}_{AC} - 1 = 0$$
$$g_D(\tau_D) = \hat{\boldsymbol{T}}(\tau_D) \cdot \hat{\boldsymbol{r}}_{DP} - 1 = 0$$

$\hat{\boldsymbol{T}}(\tau_C)$,and $\hat{\boldsymbol{T}}(\tau_D)$ are unit tangent vectors at point C and D, respectively

4 Determining pt C and D
Point C and D can be obtained by solving the following optimization prob

$$\min_{\boldsymbol{\mu}} ||g_C(\boldsymbol{\mu})||_2^2 + ||g_D(\boldsymbol{\mu})||_2^2,$$
$$\text{sub to } \boldsymbol{\mu}_l \leq \boldsymbol{\mu} \leq \boldsymbol{\mu}_u.$$

$\boldsymbol{\mu}$ is a parameter vector which contains the initial position and velocity of the CWG.

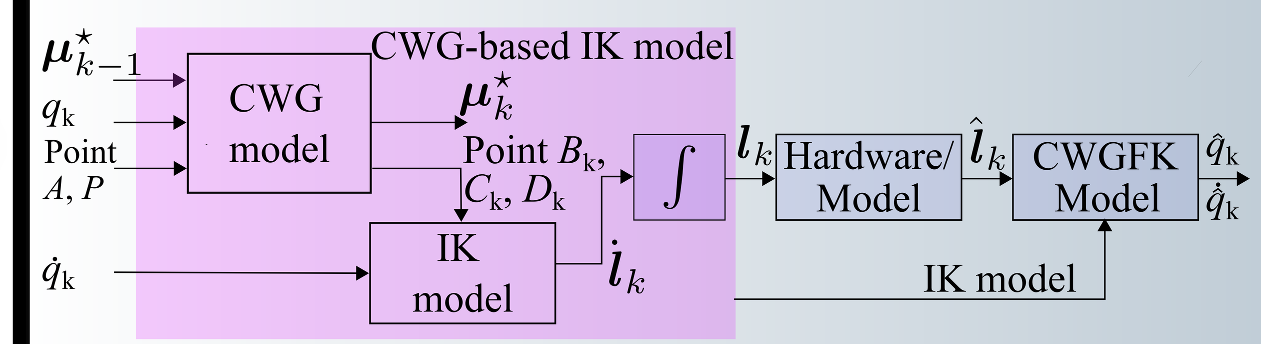
5 Cable wrapping IK length
The rate of change of cable length can be obtained from the following equation

$$\dot{l}_\gamma = \begin{bmatrix} {}^G\hat{\boldsymbol{l}}_{CA_\gamma} & \left({}^G\boldsymbol{r}_{GA_\gamma} \times {}^G\hat{\boldsymbol{l}}_{CA_\gamma}\right)^T \end{bmatrix} \begin{bmatrix} {}^G\dot{\boldsymbol{r}}_{OG} \\ {}^G\boldsymbol{\omega}_G \end{bmatrix}$$

Vectors are representd wrt frame $\{F_G\}$

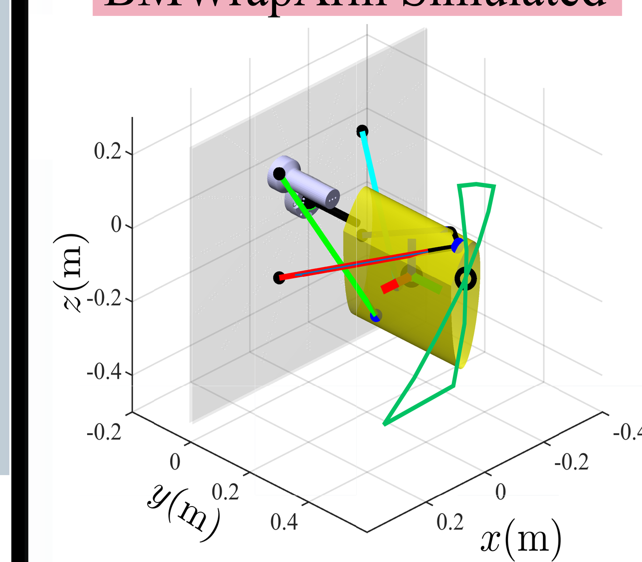
Result

FRAMEWORK

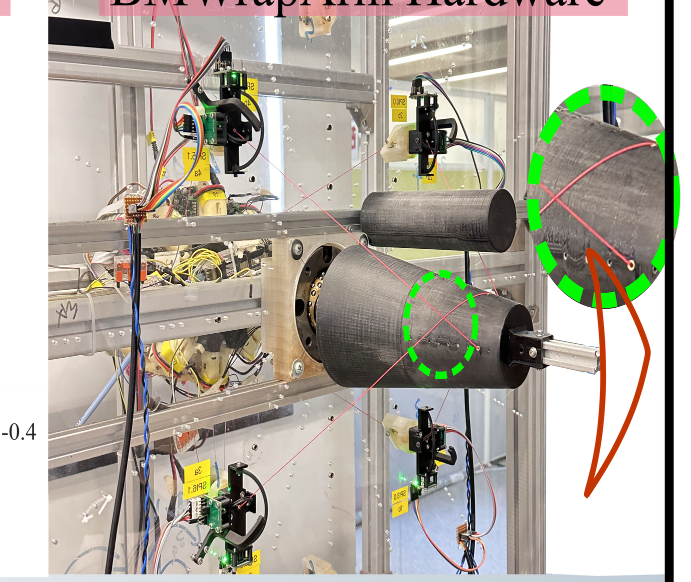


SIMULATION AND HARDWARE RESULT

BMWrapArm Simulated

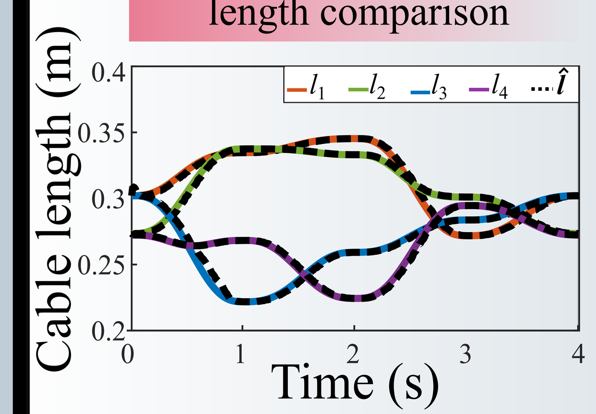


BMWrapArm Hardware

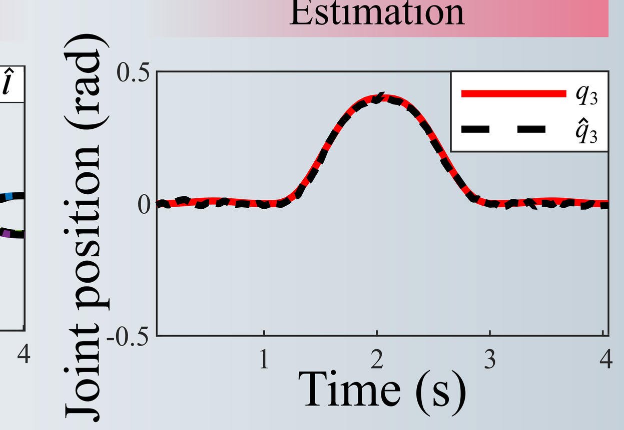


Type	Surface-type	Trajectories
Simulation	Cylinder	Arrow
Experiment	Cone-frustum	Inverted-triangle
	Almond	

IK and measured cable length comparison



CWFK Estimation



FK estimation	Root Mean Square error q_1, q_2, q_3 (rad)	
	Cone-frustum	Almond
Simulation	1.76, 1.84, 1.86 x 10^{-2}	2.80, 2.06, 3.03 x 10^{-2}
Experiment	2.27, 3.88, 1.72 x 10^{-2}	4.36, 1.66, 2.15 x 10^{-2}