Simulation of a Quadcopter with Foldable Arms

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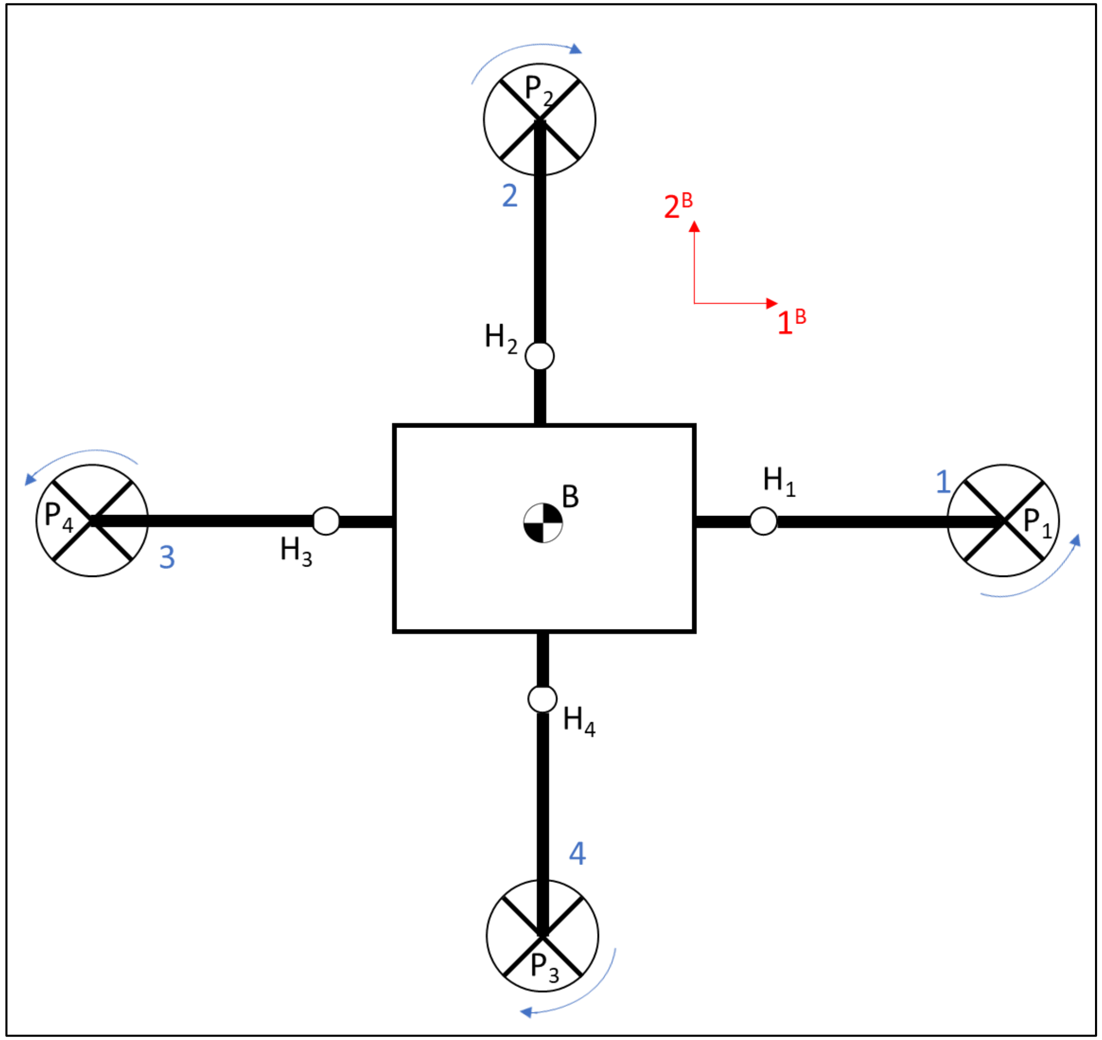
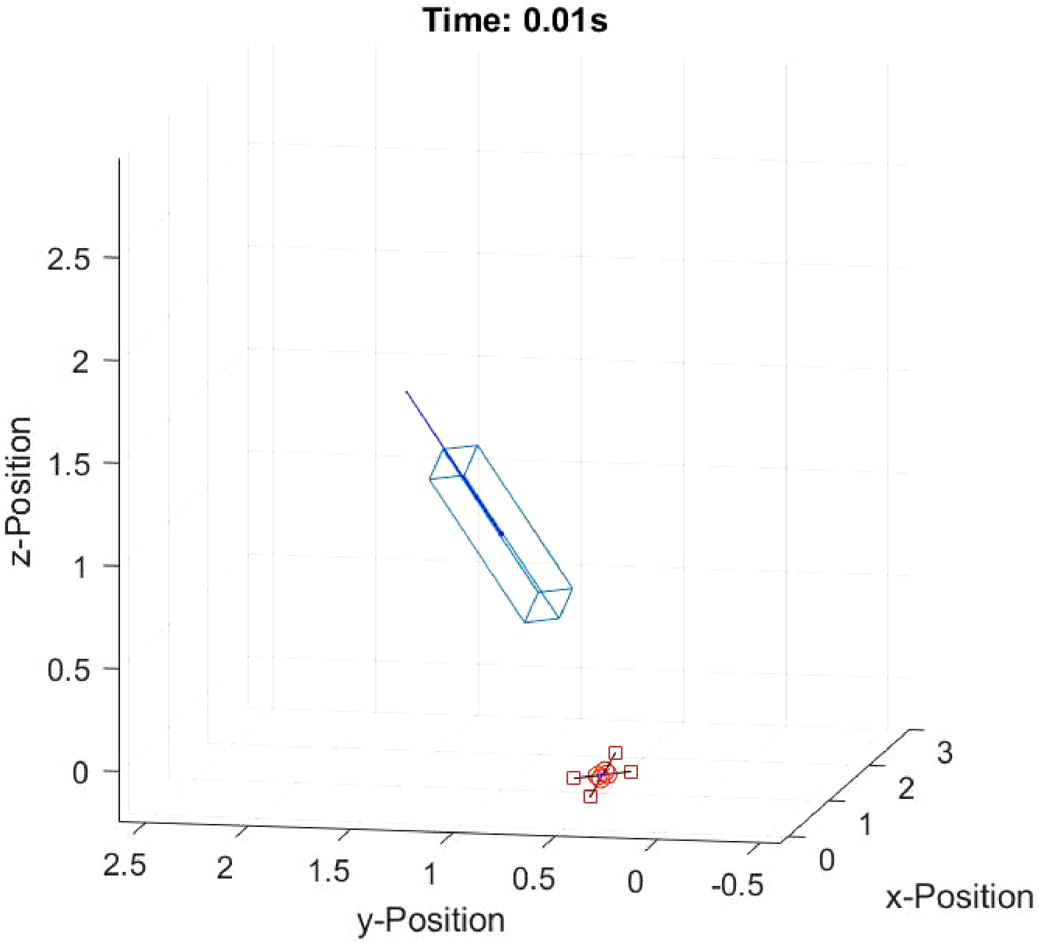
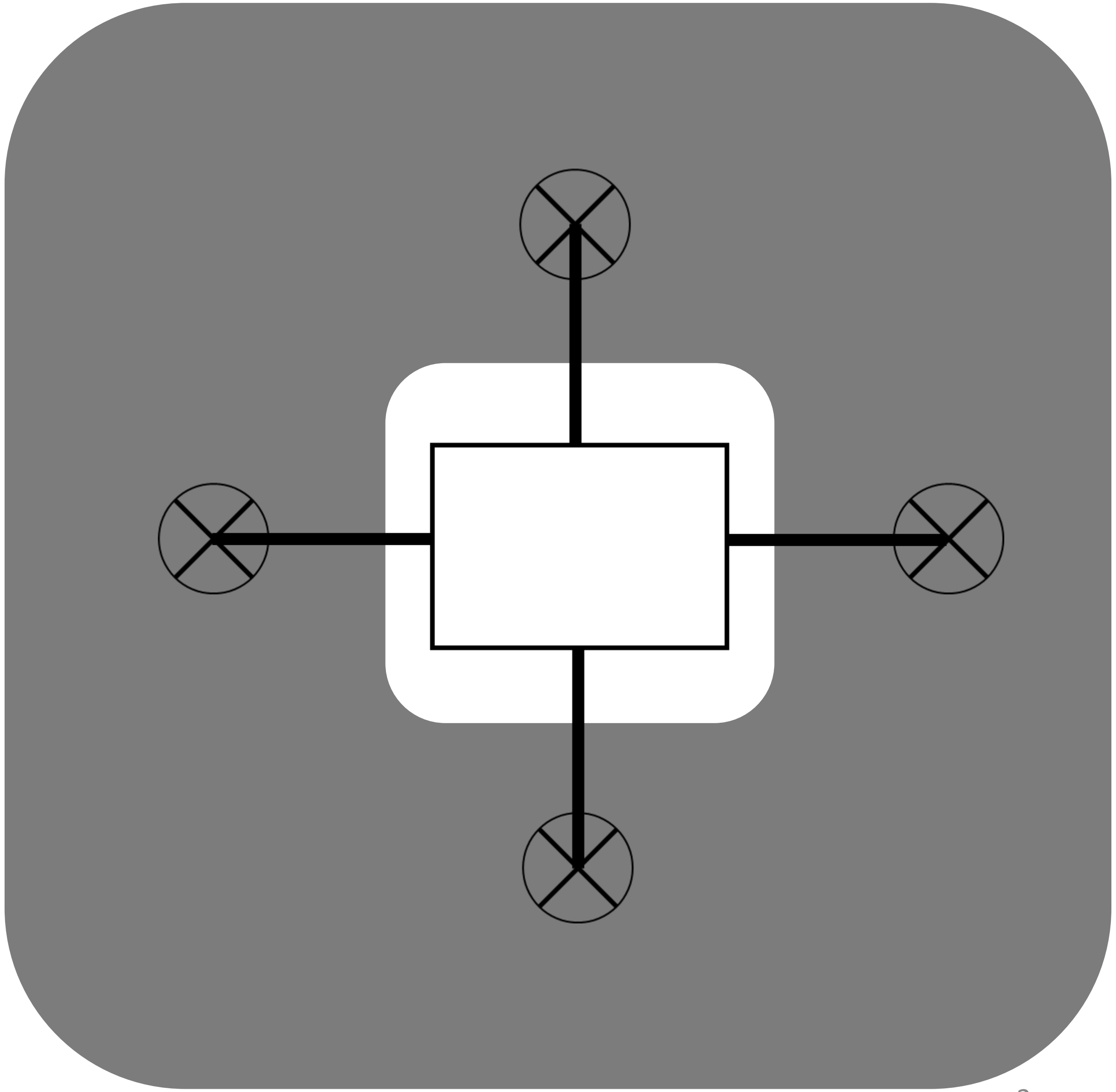
HIGH PERFORMANCE ROBOTICS

Introduction

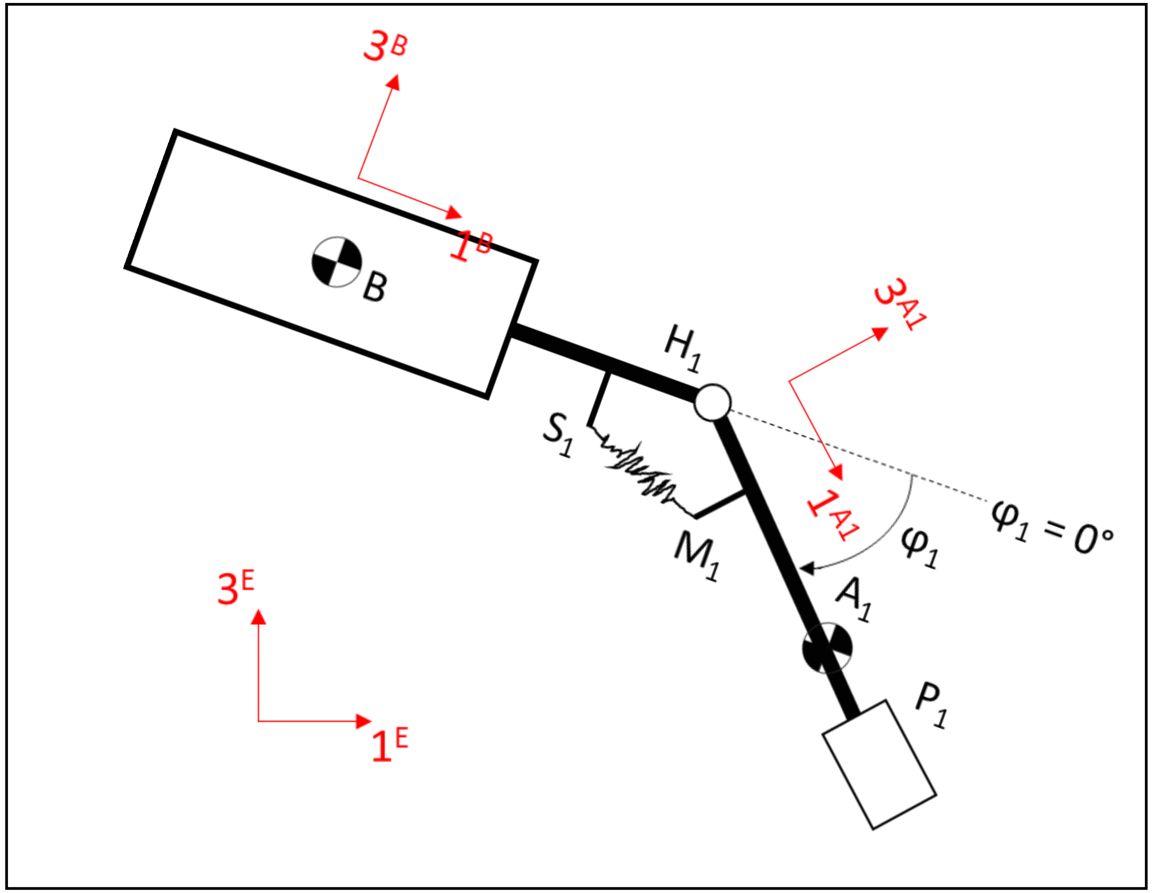


Introduction





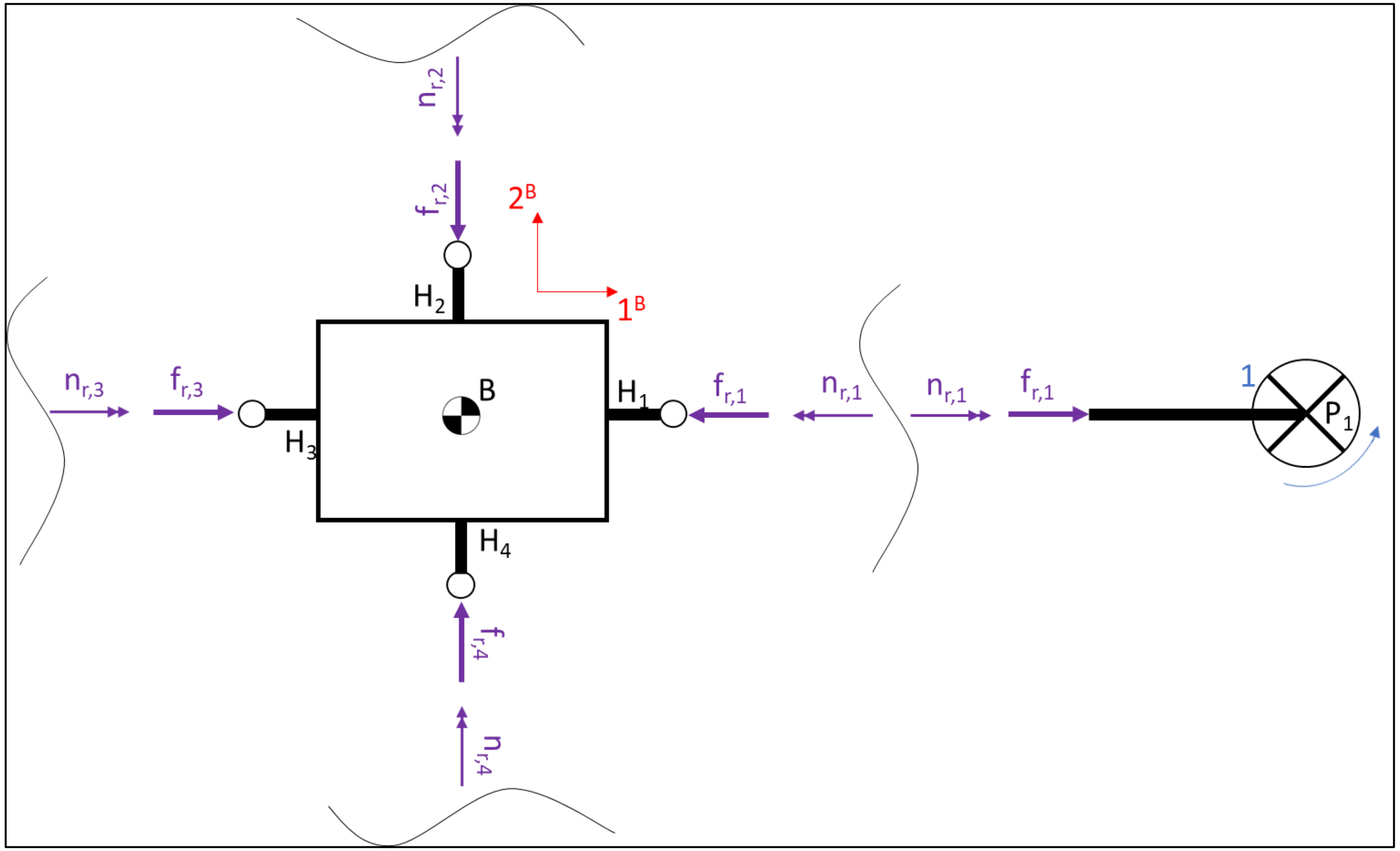
Overview of System



- Angle φ_1 being the only degree of freedom of the arm wrt. the body
- Mechanical stops at 0 and 90
- Constant force spring between body and arm

- **E:** earth-fixed frame (inertia)
- **B:** body-fixed frame
- **A_i:** arm-fixed frame

Derivation of dynamics



- Separate arms from body
- Introduce reaction torque and forces $n_{r,i}$, $f_{r,i}$
- Euler‘s and Newton‘s law for 1 arm and body

Derived Dynamics

$$\mathbf{I}_B^B D^B \omega^{BE} + \mathbf{\Omega}^{BE} \mathbf{I}_B^B \omega^{BE} = \sum_{i=1}^{4} (-\mathbf{n}_{r,i} - \mathbf{S}_{HB} \mathbf{f}_{\mathbf{r},\mathbf{i}} - \mathbf{n}_{\mathbf{s},\mathbf{i}})$$

$$m^B D^E (\mathbf{v}_B^E) = \sum_{i=1}^{4} -\mathbf{f}_{\mathbf{r},\mathbf{i}} + m^B \mathbf{g}$$

$$\begin{aligned}
&(\mathbf{I}_A^A + \mathbf{I}_P^P)(D^A \omega^{AB} + D^B \omega^{BE}) \\
&+\mathbf{I}_P^P D^P \mathbf{w}^{PA} + \mathbf{I}_P^P((\mathbf{\Omega}^{BA} + \mathbf{\Omega}^{AP})\omega^{BE} + \mathbf{\Omega}^{AP})\omega^{AB} \\
&+\mathbf{I}_A^A \mathbf{\Omega}^{BA} \omega^{BE} + (\mathbf{\Omega}^{AB} + \mathbf{\Omega}^{BE})\mathbf{I}_A^A(\omega^{AB} + \omega^{BE}) \\
&+(\mathbf{\Omega}^{PA} + \mathbf{\Omega}^{AB} + \mathbf{\Omega}^{BE})\mathbf{I}_A^A(\omega^{PA} + \omega^{AB} + \omega^{BE}) \\
&= \\
&\mathbf{n}_{\mathbf{r},\mathbf{1}} + \mathbf{S}_{H_1 A_1} \mathbf{f}_{\mathbf{r},\mathbf{1}} \\
&+\mathbf{n}_{\mathbf{p},\mathbf{1}} + \mathbf{S}_{P_1 A_1} \mathbf{f}_{\mathbf{p},\mathbf{1}} + \mathbf{n}_{\mathbf{s},\mathbf{1}}
\end{aligned}$$

$$\begin{aligned}
&m^A[D^E \mathbf{v}_B^E - \mathbf{S}_{AH} D^A \omega^{AB} - (\mathbf{s}_{AH} + \mathbf{s}_{HB}) D^B \omega^{BE} \\
&(\mathbf{\Omega}^{BE}\mathbf{\Omega}^{BE} + (\mathbf{\Omega}^{AB} + \mathbf{\Omega}^{BE})\mathbf{\Omega}^{AB} + \mathbf{\Omega}^{BE}\mathbf{\Omega}^{AB})\mathbf{s}_{AH} \\
&+\mathbf{\Omega}^{BE}\mathbf{\Omega}^{BE}\mathbf{s}_{HB}] \\
&= \\
&\mathbf{f}_{\mathbf{p},\mathbf{1}} + \mathbf{f}_{\mathbf{r},\mathbf{1}} + m^A \mathbf{g}
\end{aligned}$$

X 4

$$[D^B \omega^{BE}]^B = [\dot{p} \quad \dot{q} \quad \dot{r}]'$$

$$[D^E v_B^E]^E = [a_1 \quad a_2 \quad a_3]'$$

$$[D^{A_i} \omega^{A_i B}]^{A_i} = [0 \quad \ddot{\varphi}_i \quad 0]'$$

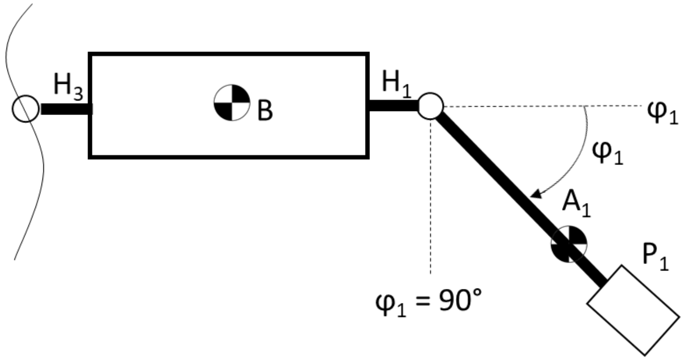
$$[f_{r,i}]^{A_i} = [f_{1,i} \quad f_{2,i} \quad f_{3,i}]'$$

$$[n_{r,i}]^{A_i} = [n_{1,i} \quad n_{2,i} \quad n_{3,i}]'$$

X 4

Extra Constraint

Case 1:



$$[D^B\omega^{BE}]^B = [\dot{p} \quad \dot{q} \quad \dot{r}]'$$

$$[D^E v_B^E]^E = [a_1 \quad a_2 \quad a_3]'$$

$$[D^{A_i}\omega^{A_iB}]^{A_i} = [0 \quad \ddot{\varphi}_i \quad 0]'$$

$$[f_{r,i}]^{A_i} = [f_{1,i} \quad f_{2,i} \quad f_{3,i}]'$$

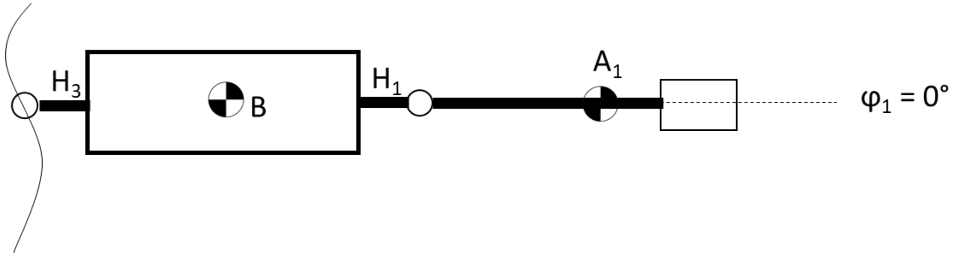
$$[n_{r,i}]^{A_i} = [n_{1,i} \quad \underset{0}{\underline{\underline{\cancel{n_{2,i}}}}} \quad n_{3,i}]'$$

X 4

30 unknowns

30 equations

Case 2:



$$[D^B\omega^{BE}]^B = [\dot{p} \quad \dot{q} \quad \dot{r}]'$$

$$[D^E v_B^E]^E = [a_1 \quad a_2 \quad a_3]'$$

$$[D^{A_i}\omega^{A_iB}]^{A_i} = [0 \quad \underset{0}{\underline{\underline{\cancel{\ddot{\varphi}_i}}}} \quad 0]'$$

$$[f_{r,i}]^{A_i} = [f_{1,i} \quad f_{2,i} \quad f_{3,i}]'$$

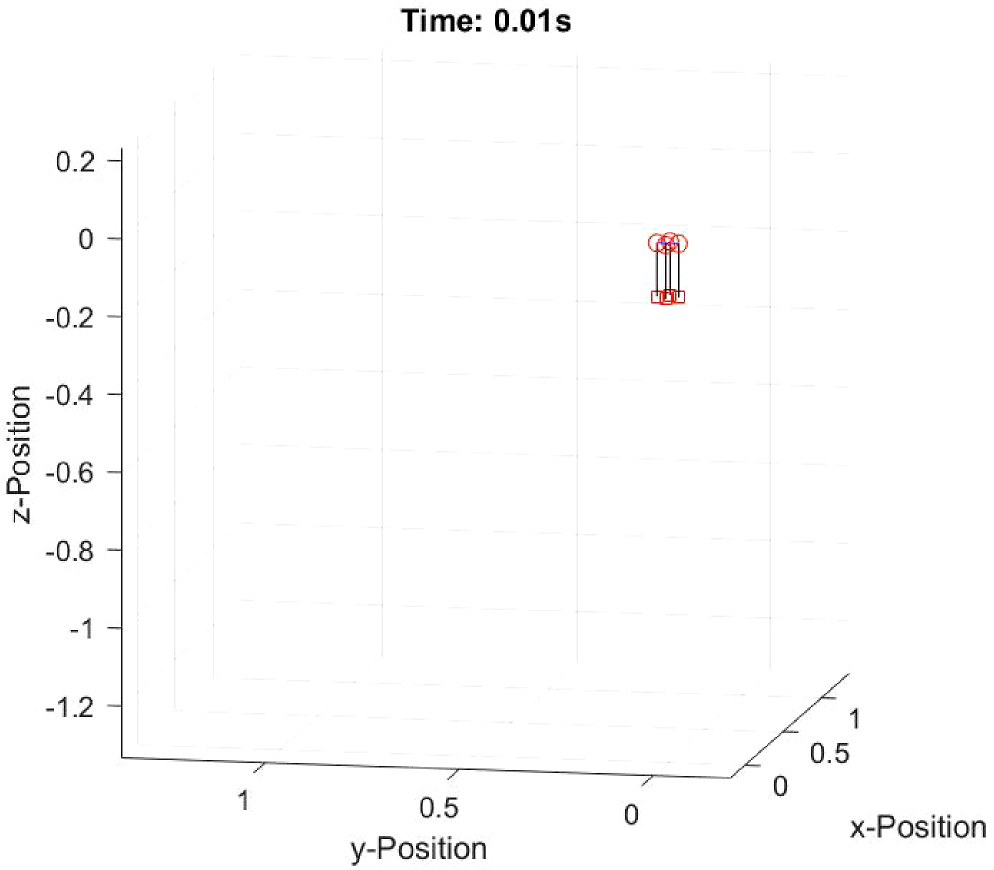
$$[n_{r,i}]^{A_i} = [n_{1,i} \quad n_{2,i} \quad n_{3,i}]'$$

X 4

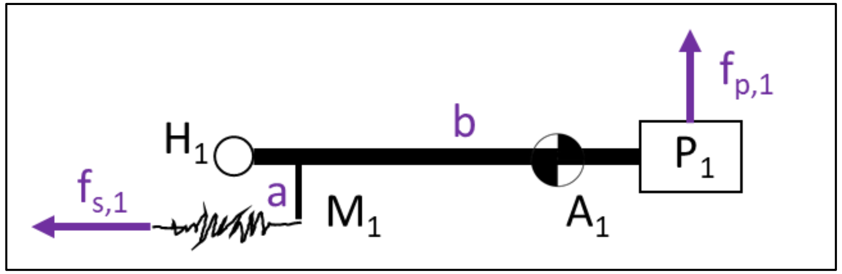
Summary Simulation

1. **Initialize** system at k = 0
2. **Set propeller speed** for each motor→calculate motor thrust/torque and angular acceleration of the propeller
3. **Calculate** accelerations, rection forces and torques depending on current state of the arms by solving linear set of algebraic equations
4. Calculate angular/translational velocity, position and orientation through **Euler integration**
5. Check for **current state** of the arms (folded or stretched)
6. **Repeat** from step 2

Unfold/Hover/Fold

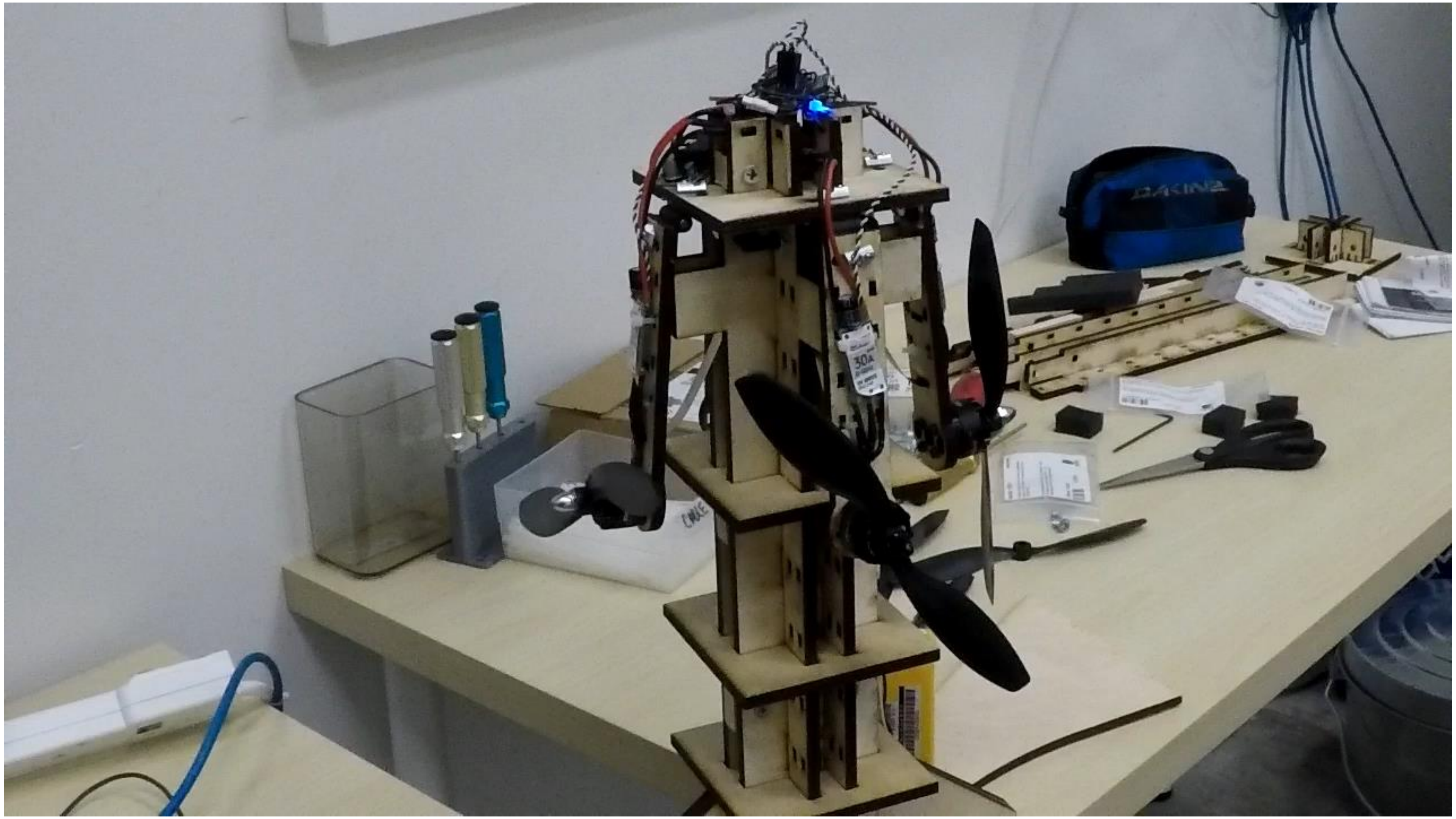


1. Unfold quadcopter by setting motor thrust to 100%
2. Use normal quadcopter controller to hover
3. Fold quadcopter by setting all motor thrust to zero

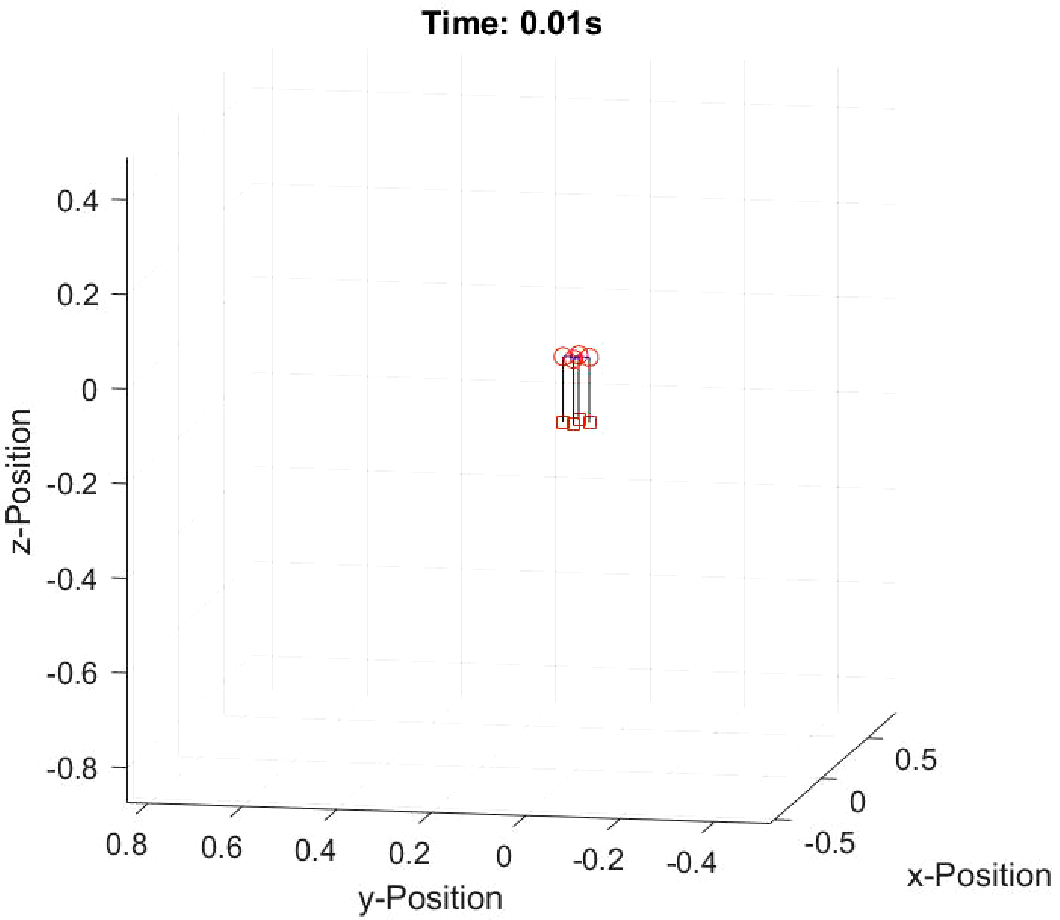


$$minThrust = f_{s,1} \cdot \frac{a}{b}$$

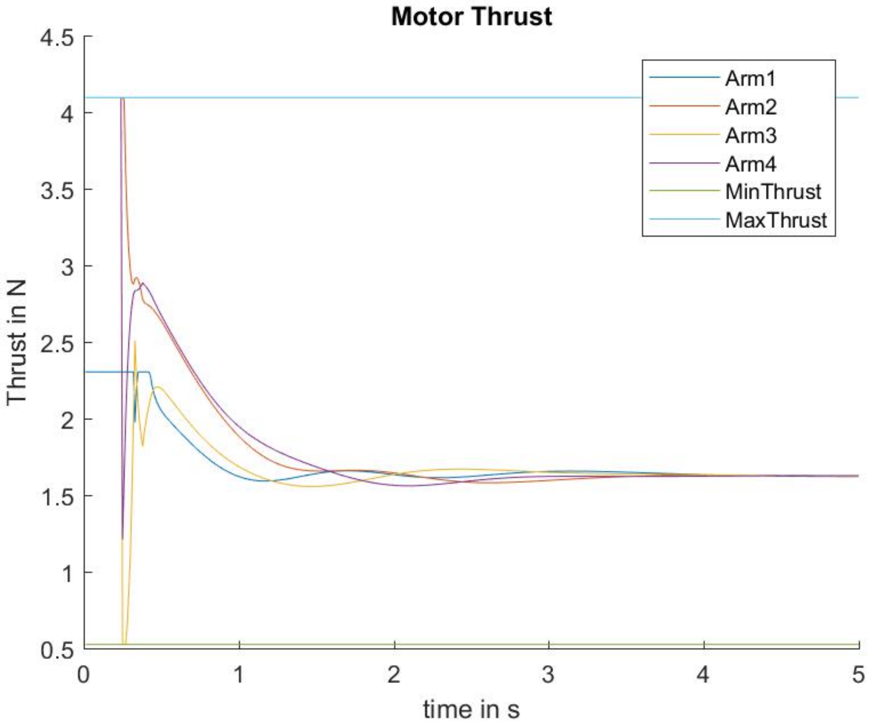
Physical Test



Asymmetric thrust

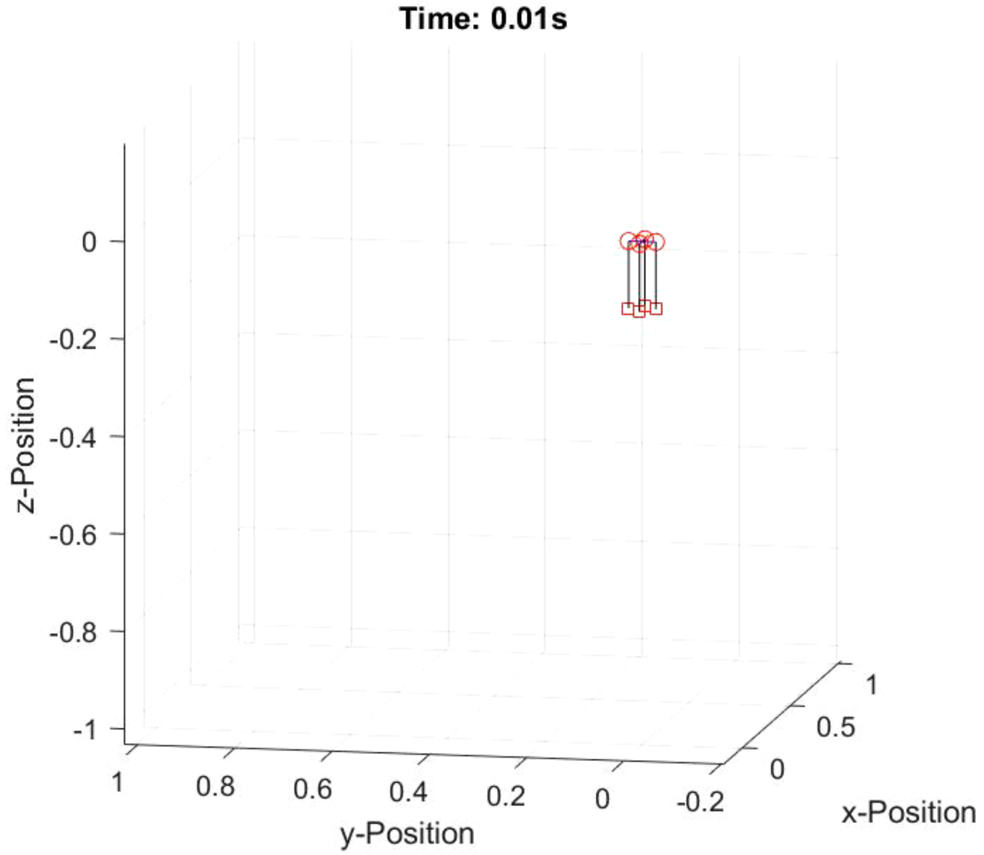


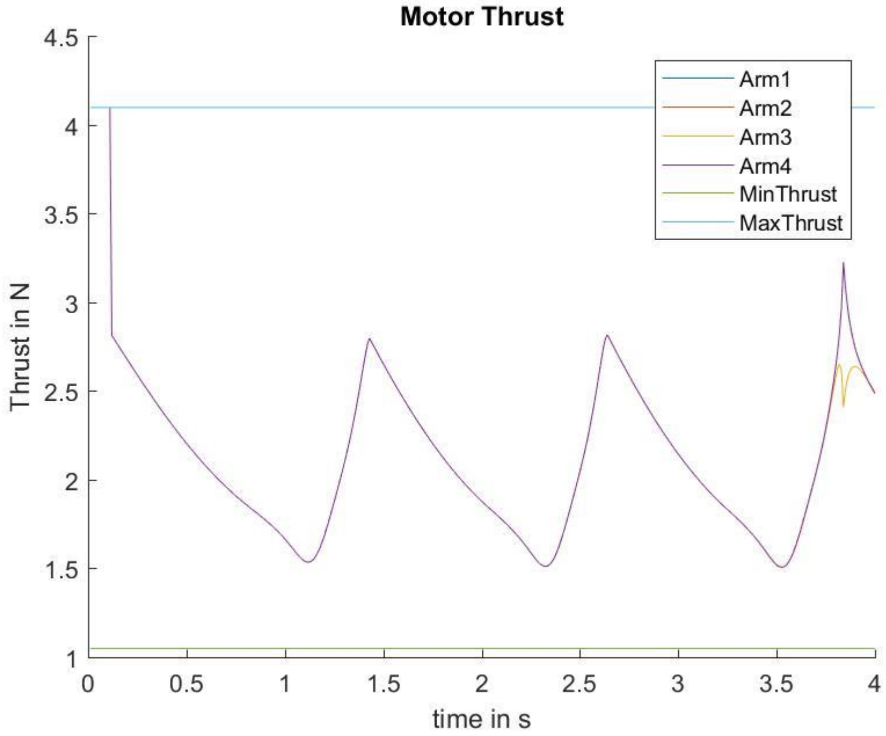
Disturbance in max. motor thrust of Arm 1: 25% less



Minimum Threshold

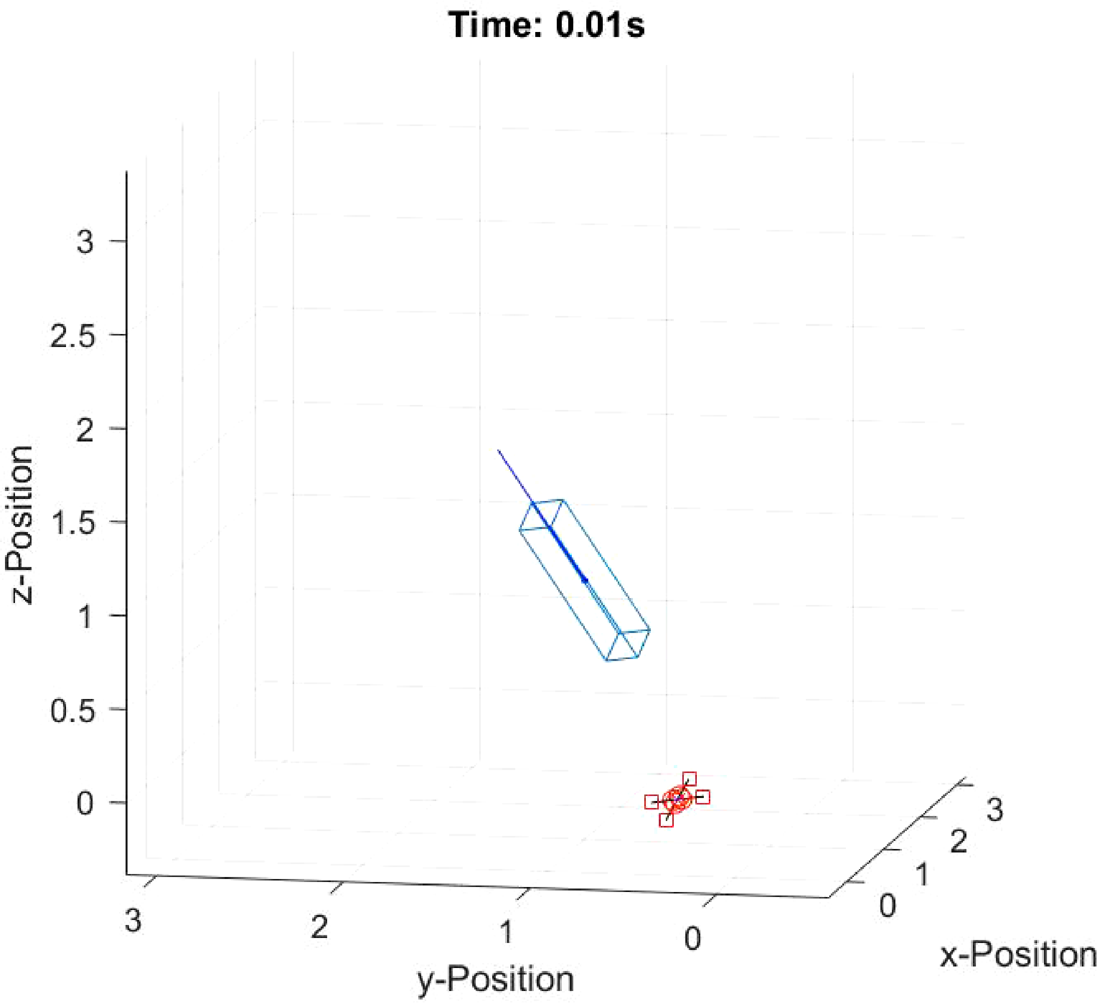
springForce = 4
minThrust = 1.0483
hoverThrust = 1.6236





Gap with initial angular velocity

Set initial angular velocity to [0, 2, 0] rad/s, when folding arms



Next Steps

- Import simulation in lab code (C++) and test with „real“ disturbances
- Improve algorithm for generating „Gap-trajectory“
- Finish and fabricate physical design and test control strategies on real system

Thank you for listening!

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