Computational Design of a Bird-Inspired Perching Landing Gear Mechanism

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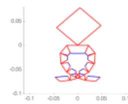


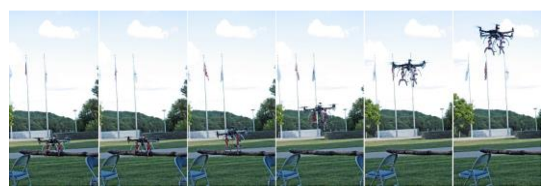
Background

- Quadcopters operating in crowded environments (e.g. city, forest)
- Growing interest in bird-like UAV's
- Technology is reaching the point where bird-sized, bird-like UAV's can be built
- Biomimicry is a guide for new capabilities

From MAV-2015 AFRL's Vision for Bird Sized UAV

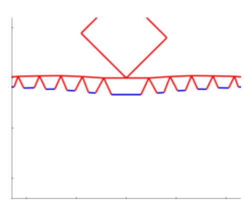
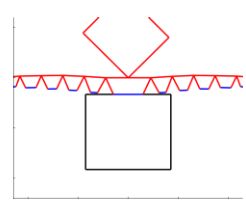
Prototype System: 4-Bar Linkage with Cable-Tendon-Driven Underactuated Feet


Prototype System: Demonstration of Take-Off from a Perch

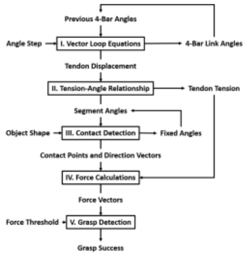


Our Design Tool Predicts Whether UAV Can Perch on a Target of Given Size/Shape

Design Tool Simulates Grasping

Hybrid Empirical-Numerical Model



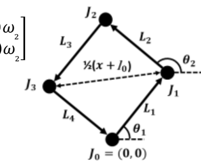
Step I: Determine Tendon Displacement

As the UAV lands the 4-bar linkage collapses, causing displacement in the cable tendon

$$\begin{bmatrix}\omega_3\\ \omega_4\end{bmatrix} = \begin{bmatrix}L_3\sin(\theta_3) & L_4\sin(\theta_4)\\ L_3\cos(\theta_3) & L_4\cos(\theta_4)\end{bmatrix}^{-1}\begin{bmatrix}-L_2\,sin(\theta_2)\omega_2\\ -L_2\,cos(\theta_2)\omega_2\end{bmatrix}$$

$$\boldsymbol{J}_n = \sum_{i=1}^{n} L_i\cos(\theta_i)\hat{\imath} + L_i\sin(\theta_i)\,\hat{\jmath}$$

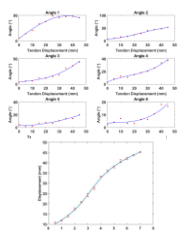
$$x = 2|\boldsymbol{J}_1 - \boldsymbol{J}_3| - l_0$$ <- tendon displacement



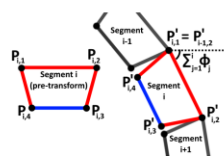
Step II: Empirically Determine Tendon Tension and Angular Rotation of Foot Segments

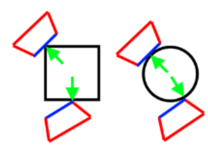

Tendon Tension


Foot Segment Angles



Step III: Detect Contact Between Foot Segments and Target





Step IV: Calculate Contact Forces

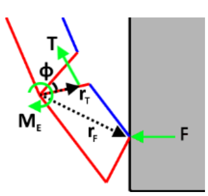
$$M_T(x) = |\boldsymbol{r_T}|T(x)\cos(\tfrac{1}{2}\phi_{max} - \tfrac{1}{2}\phi(x))$$

$$M_F(x) = M_T(x) - M_E(x) = M_T(x) - M_T(x_c)$$

$$= |\boldsymbol{r}_T|\big(T(x) - T(x_c)\big)\cos(\frac{1}{2}\phi_{max} - \frac{1}{2}\phi(x))$$

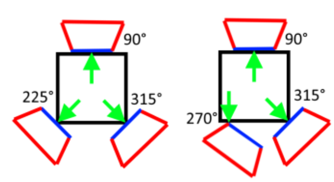
$$M_{F_{net}} = M_F - \sum_{j=i+1}^{N}\left|\boldsymbol{r}_{\boldsymbol{F}_{ij}} \times \boldsymbol{F}_j\right|$$

$$F_i = \frac{M_{F_{net}}}{\left|\boldsymbol{r}_{\boldsymbol{F}_{ii}} \times \widehat{\boldsymbol{F}}_i\right|}$$ <- contact force at a specific point



Step V: Evaluate Grasp

- Apply force thresholds
- Determine if system is fully constrained
- Compute necessary UAV weight to achieve final tendon tension

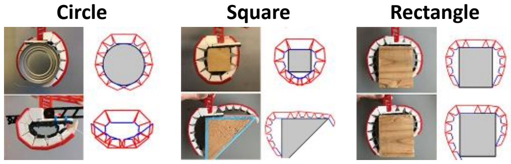


Successful Grasp

Failed Grasp

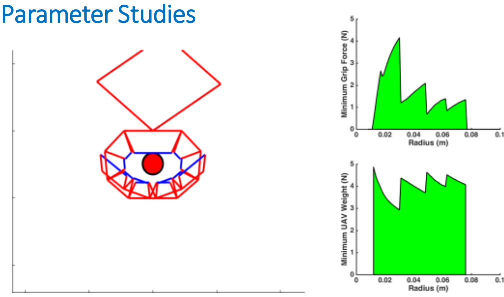
Validated Grasping Kinematics

Circle Square Rectangle

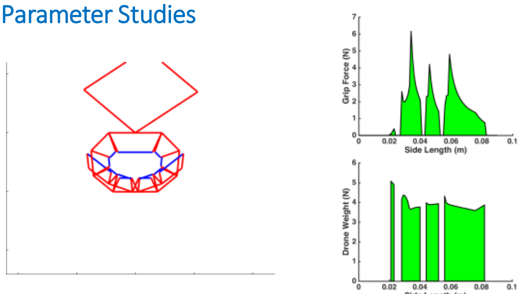


Empty Triangle Off-Center Rectangle

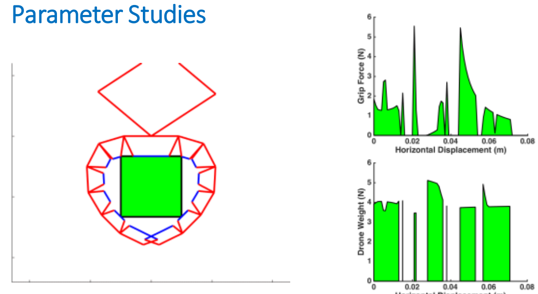
Parameter Studies



Parameter Studies



Parameter Studies



Conclusion and Future Work

Accomplished:

- Validated empirical-numerical model of landing gear kinematics
- Predicted grip forces and grasping criteria
- Swept model over a range of parameters to extract useful data for designers

Next Steps:

- Experimentally validate computed force magnitudes
- Computing relationships directly from elasticity measurements
- Expand design space to optimize parameters over a wider range of targets

Acknowledgements

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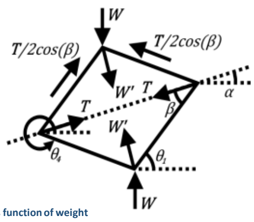
UAV Weight Related to Tendon Tension

$W = T\tan(\beta)\cos(\alpha)$

$\alpha = \frac{\theta_1 + \theta_4}{2} - 180°$ $\beta = \frac{\theta_1 - \theta_4}{2} + 180°$

$W_{max} = -T_{max}\tan\left(\frac{\theta_1 - \theta_4}{2}\right)\cos\left(\frac{\theta_1 + \theta_4}{2}\right)$



$T_{max} = \frac{-W_{max}}{\tan\left(\frac{\theta_1 - \theta_4}{2}\right)\cos\left(\frac{\theta_1 + \theta_4}{2}\right)}$ <- tension as function of weight