Design and Modeling of a Custom Unmanned Aerial Manipulator for Bridge Inspection

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Motivation

- To conserve resources, bridges get inspected only once every two years, resulting bridges to get more risk of structural damages on the long run [1].
- Ultrasonic sensors are used to collect structural integrity data. A technician must climb the bridge or else use a cherry picker to access hard to reach areas. This results more exposure to injuries and costs a lot of money and time.
- Current Unmanned Aerial Vehicles (UAVs) implemented in this field do not have enough degrees of freedom (4) to compensate for errors in roll and pitch, resulting inaccurate positioning when collecting data.

Goal : To build an aerial manipulator and a custom UAV that is small, lightweight, and stable that can be used to take measurements of the bridges and save resources.

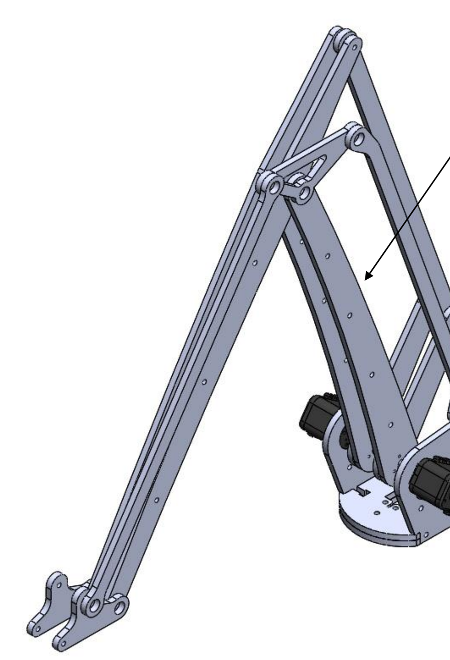
Tilted multirotor UAV

UAV Specifications

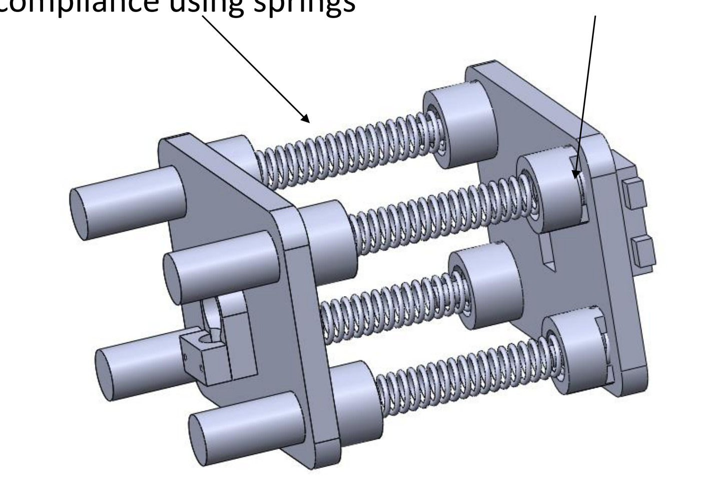
- The specification of the UAV were decided using a tool in Bershadsky et al [2] to size the parameters and the tilt angle. The UAV's rotors are tilted by 30 deg and can carry an additional payload of 2 kg for 5 minutes.

Parameter	Value
Diameter	685 *mm*
Mass	4.5 *kg*
Hover time	30 *min*
Battery configuration	6*S*
Battery capacity	16000 *mAh*
Propeller diameter	13"
Propeller pitch	4.4"
K_v	700 *RPM*/*V*

Arm Design



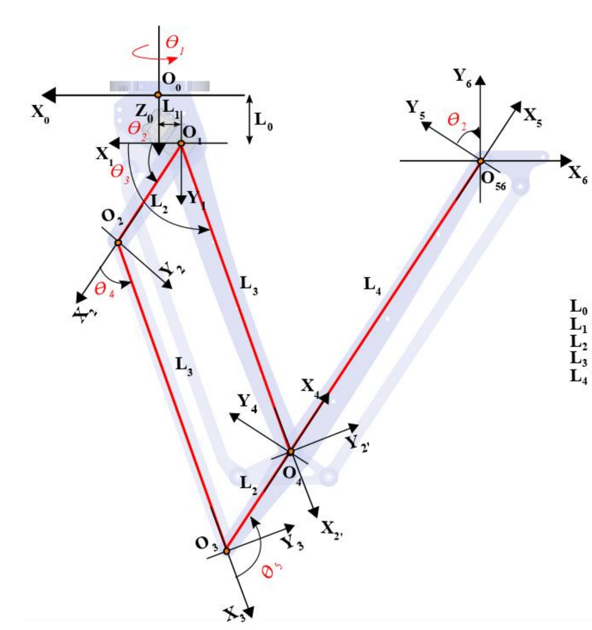
(a)



(b)

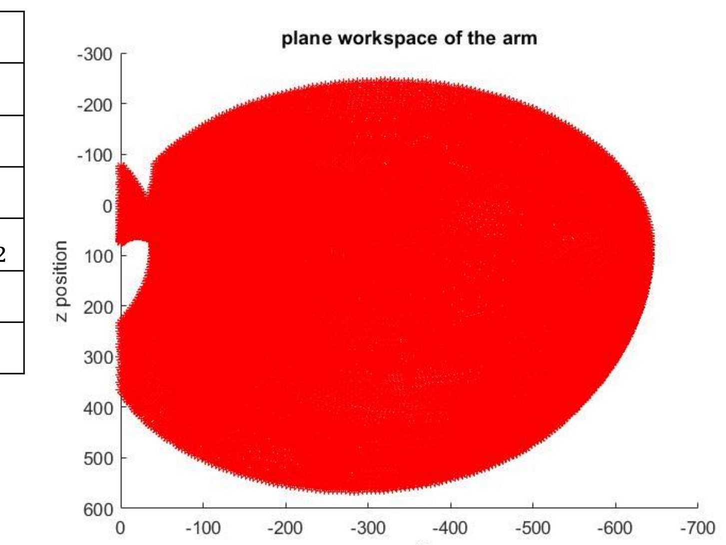
(a) The benefit of the parallelogram mechanism is to allow center of mass to be as close as possible to the base of the arm resulting less inertia on the UAV when the arm does its task. (b) The end effector's FSRs under each spring give feedback to the arm about the contact forces.

Forward Kinematics



Link	a_i	α_i	d_i	θ_i
$Link\ O_0O_1$	$-L_1$	90^0	L_0	θ_1
$Link\ O_1O_2$	L_2	0	0	θ_2
$Link\ O_2O_3$	L_3	0	0	$\theta_3 - \theta_2$
$Link\ O_3O_4$	L_2	0	0	$180^0 - \theta_3 + \theta_2$
$Link\ O_1O_4$	L_3	0	0	θ_3
$Link\ O_4O_{56}$	L_4	0	0	0

$$A_{06} = \begin{bmatrix} -c_{\theta_1} & 0 & s_{\theta_1} & L_3 c_{\theta_1} c_{\theta_3} - L_1 c_{\theta_1} - L_4 c_{\theta_1} c_{\theta_3} \\ -s_{\theta_1} & 0 & -c_{\theta_1} & L_3 s_{\theta_1} c_{\theta_3} - L_1 s_{\theta_1} - L_4 s_{\theta_1} c_{\theta_3} \\ 0 & -1 & 0 & L_3 c_{\theta_3} - L_1 - L_4 c_{\theta_2} \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

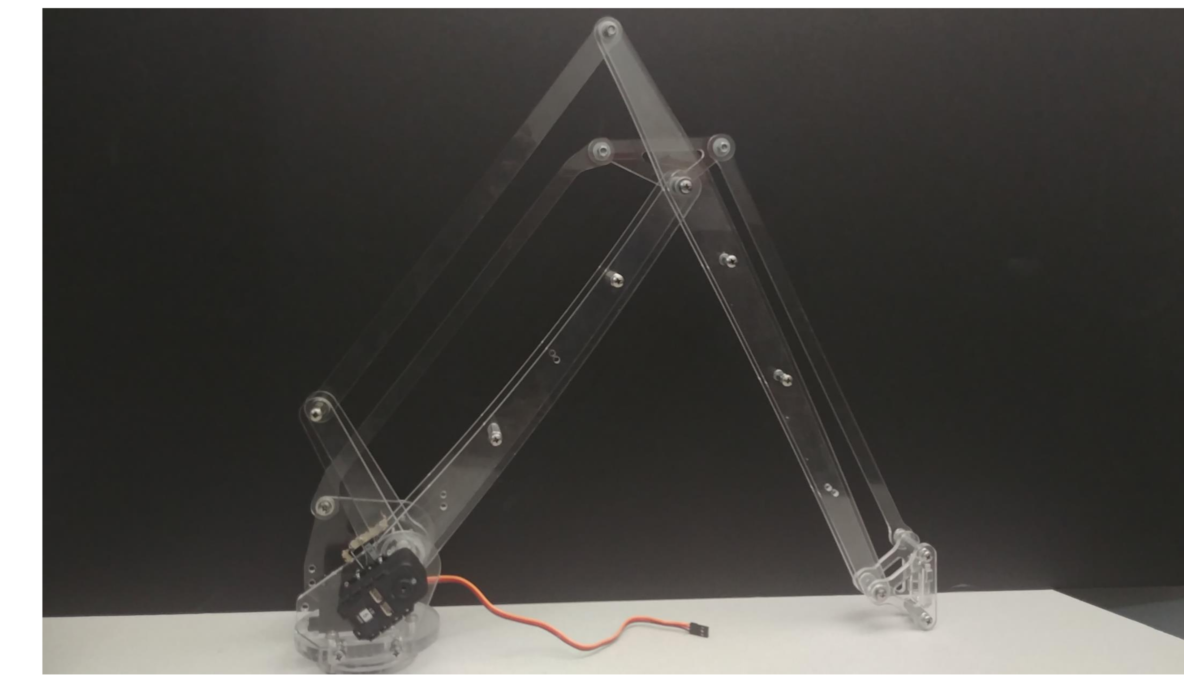


The benefit of the parallelogram mechanism is to prevent the end effector's face from rotating which is more stable for inspecting the bridge surface. The maximum reach of the arm is approximately 640 mm from the center of the drone with an offset from the propellers equal to 200 mm (without the end effector).

UAV Control : following pitch and roll correctly with tilted rotors

The assembly was tested in altitude mode using an RC controller. The control was able to correctly follow pitch and roll setpoints, even with the tilted rotor setup.

Arm Physical Model



Future Work

- Implement position control with production of lateral forces to move without changing roll and pitch.
- Implement Control of the arm that can compensate for errors in position and keep the sensor on the same point.
- Combine data from the camera and the laser to estimate distance from the wall and get texture data of the bridges.

References

[1] C. of Pennsylvania, Bridge information, Available at http://www.penndot.gov/ProjectAndPrograms/Bridges/Pages/default.aspx (2018/07/02).

[2] Bershadsky, D., Haviland, S., and Johnson, E. N. (2016). Electric multirotor propulsion system sizing for performance prediction and design optimization. In Proceedings of the AIAA Scitech Design Processes and Tools Conference. (2018/7/02)

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