Smart Control of 2 Degree of Freedom Helicopters

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Objective and Contribution

Objective
- Develop a platform allowing mobile devices to control the motion of a group of helicopters

Contribution
- Determine trade-offs between traditional control techniques and machine learning
- Multi-Helicopter Application

Applications
- Teleoperation approach to search and rescue
- Aerial turbulence resistance

Problem Setup

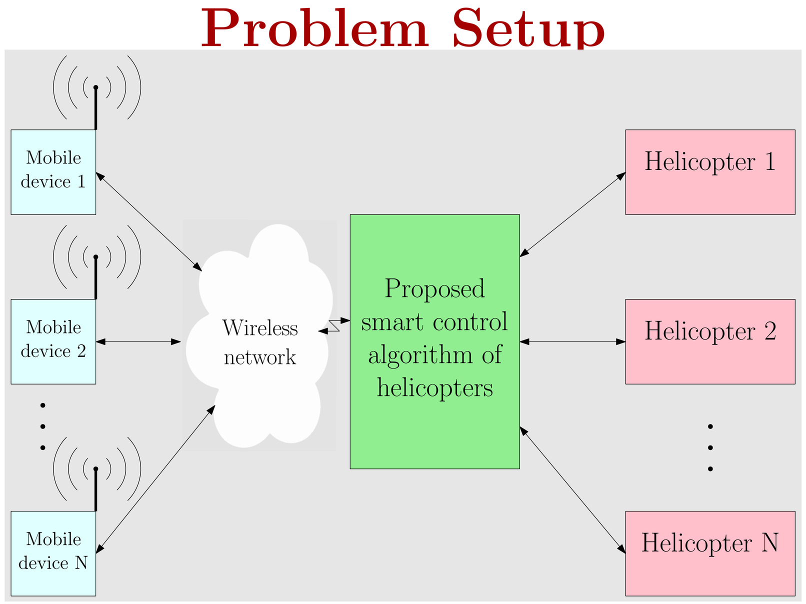

Figure 1: High level architecture of the proposed system.

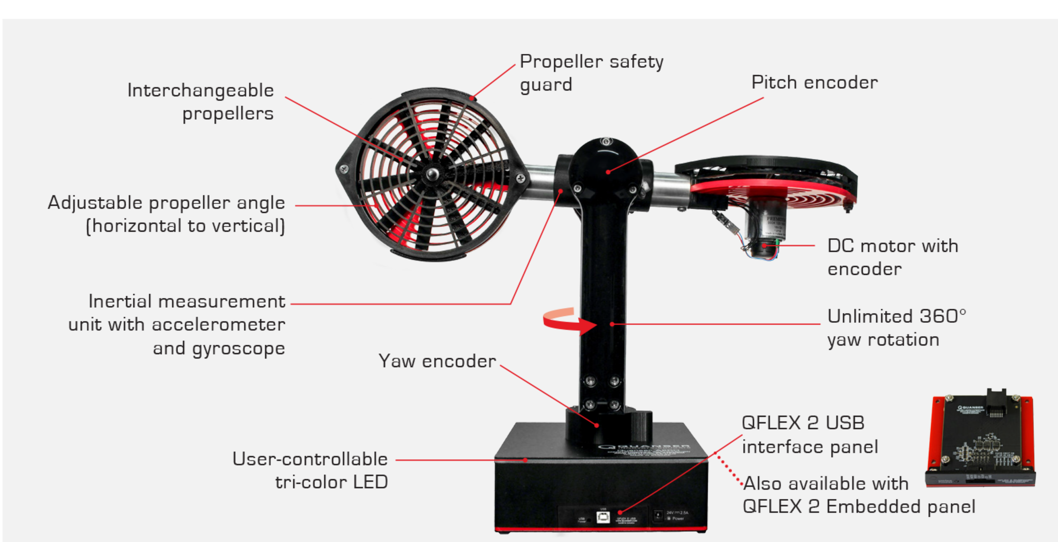

Figure 2: 2-DOF helicopter (Quanser Aero).

- State-space representation of 2-DOF helicopter

$$\begin{bmatrix}\dot\theta\\ \dot\psi\\ \ddot\theta\\ \ddot\psi\end{bmatrix} = \begin{bmatrix}0 & 0 & 1 & 0\\ 0 & 0 & 0 & 1\\ 0 & -K_{sp}/J_p & -D_p/J_p & 0\\ 0 & 0 & 1 & -D_y/J_y\end{bmatrix}\begin{bmatrix}\theta\\ \psi\\ \dot\theta\\ \dot\psi\end{bmatrix} + \begin{bmatrix}0 & 0\\ 0 & 0\\ K_{pp}/J_p & K_{py}/J_p\\ K_{yp}/J_y & K_{yy}/J_y\end{bmatrix}\begin{bmatrix}V_p\\ V_y\end{bmatrix}$$

Motion (Trajectory) Control Algorithm

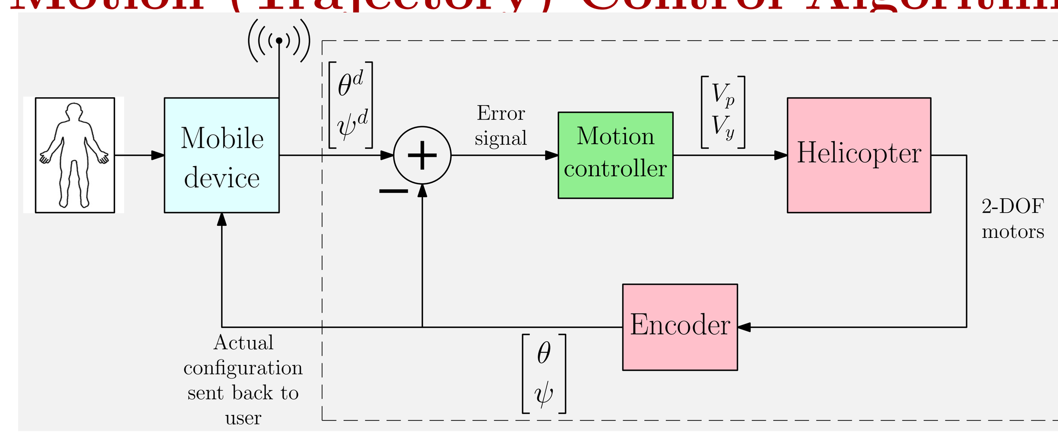

Figure 3: A desired orientation is given by a user. The difference between this input and the actual position is calculated. The controller the calculates the proper amount of voltage to apply to the DC motors.

1. Employ state-space representation of 2-DOF helicopter:
$$\dot{\mathbf{x}} = \mathbf{A}\mathbf{x} + \mathbf{B}\mathbf{u}$$
2. Use state feedback law
$$\mathbf{u} = -\mathbf{K}\mathbf{x}$$
to minimize the quadratic cost function:
$$J(\mathbf{u}) = \int_0^\infty (\mathbf{x}^T\mathbf{Q}\mathbf{x} + \mathbf{u}^T\mathbf{R}\mathbf{u} + 2\mathbf{x}^T\mathbf{N}\mathbf{u})\mathrm{d}t$$
3. Find the solution $\mathbf{S}$ to the Riccati equation
$$\mathbf{A}^T\mathbf{S} + \mathbf{S}\mathbf{A} - (\mathbf{S}\mathbf{B} + \mathbf{N})\mathbf{R}^{-1}(\mathbf{B}^T\mathbf{S} + \mathbf{N}^T) + \mathbf{Q} = 0$$
4. Calculate gain, $\mathbf{K}$
$$\mathbf{K} = \mathbf{R}^{-1}(\mathbf{B}^T\mathbf{S} + \mathbf{N}^T)$$

Optimal Noise Resistant Control Algorithm

- Utilizes gain calculated in LQR
- Added Kalman filter to reduce external disturbances to the system

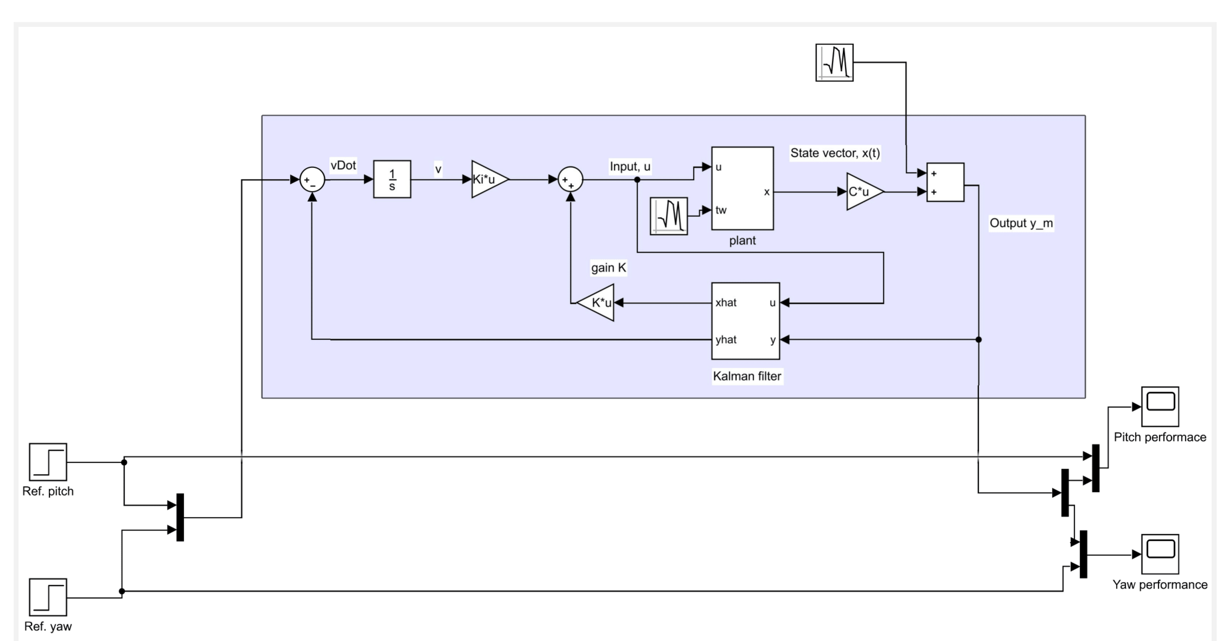

Figure 4: Noise resistant 2-DOF helicopter model.

Reinforcement Learning Algorithm

- Uses neural network based on difference between desired and actual orientation to determine optimal gain

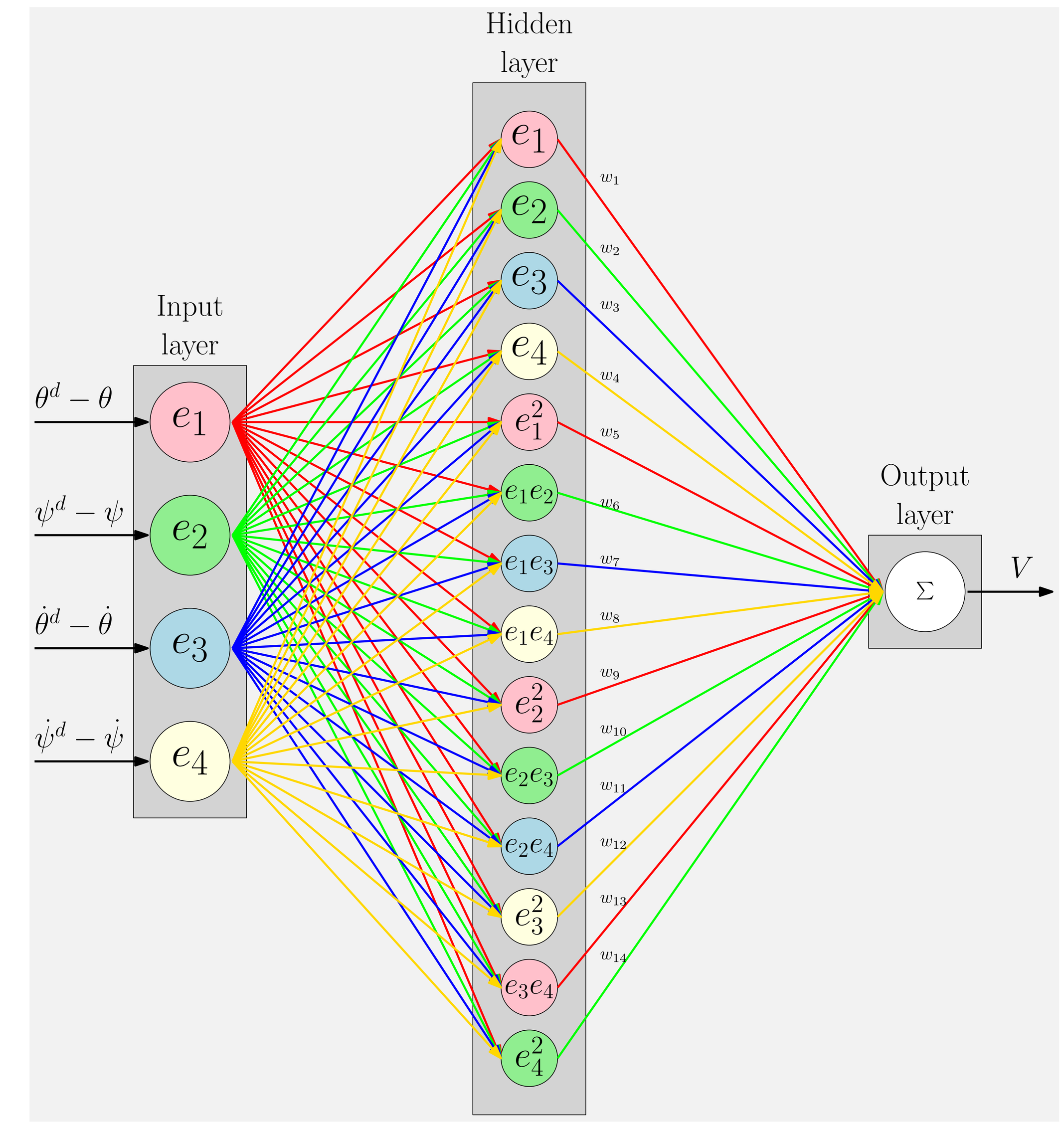

Figure 5: ADP Neural Network

Simulation Results

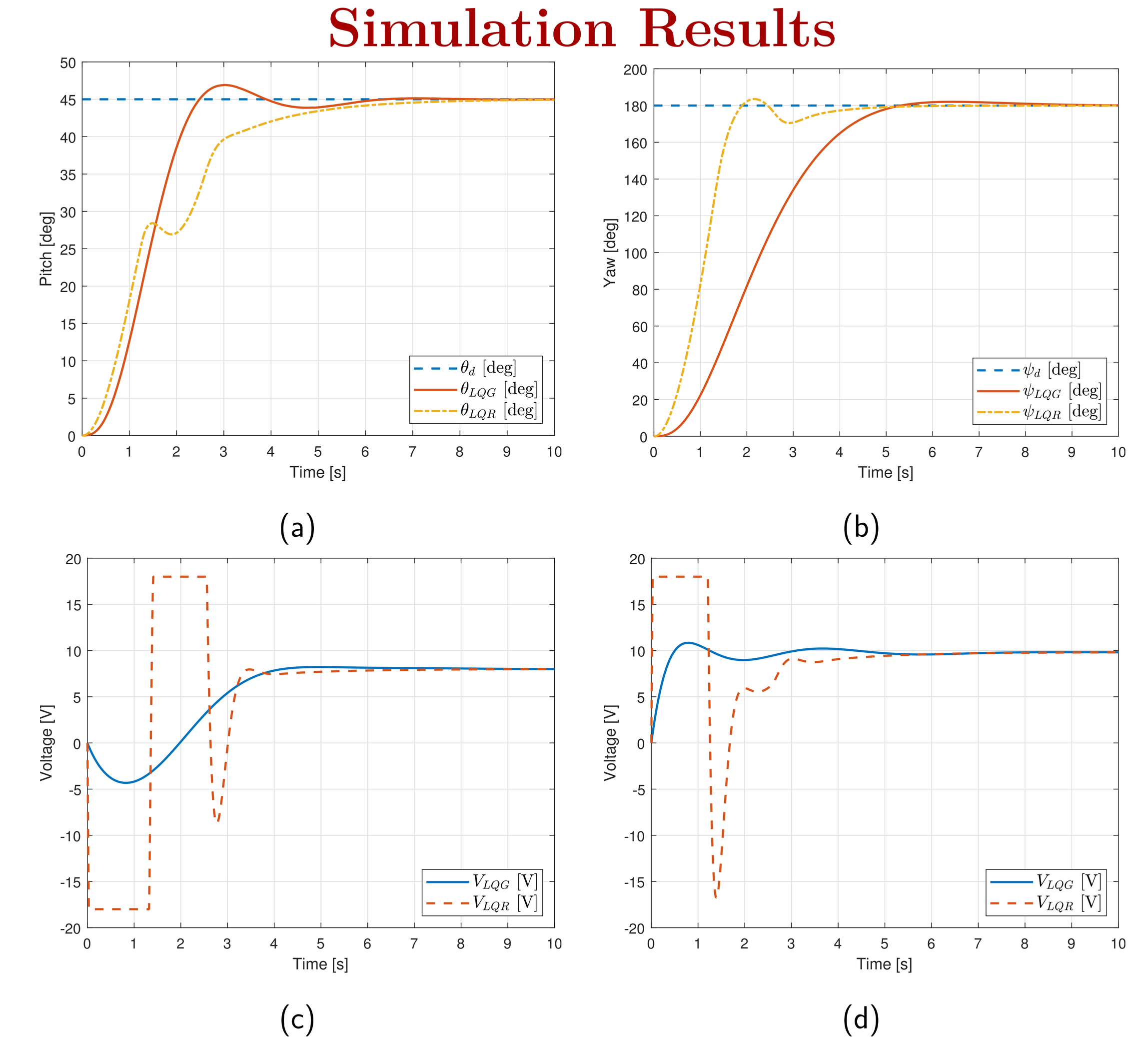

Figure 6: A comparison between LQG and LQR control for a step input is shown for (a) the main rotor and (b) the tail rotor and the corresponding voltages in (c) and (d)

Experimental Results

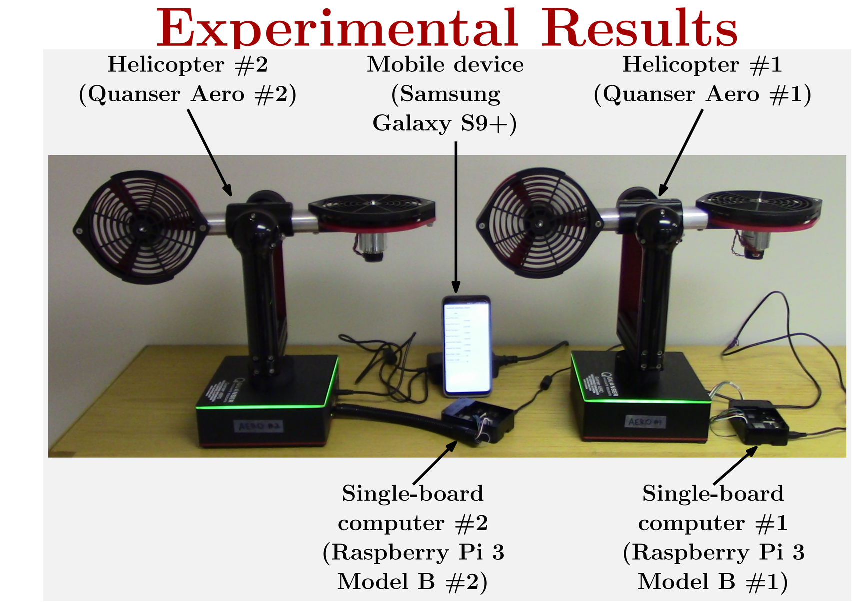

Figure 7: Experimental Setup

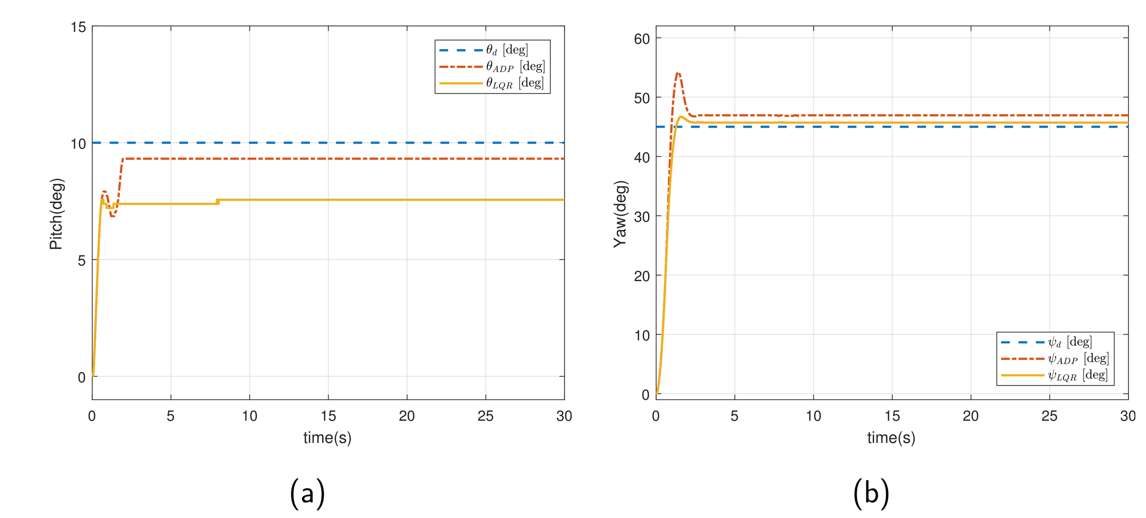

Figure 8: ADP experimental results for (a) the main rotor and (b) the tail rotor given a step input

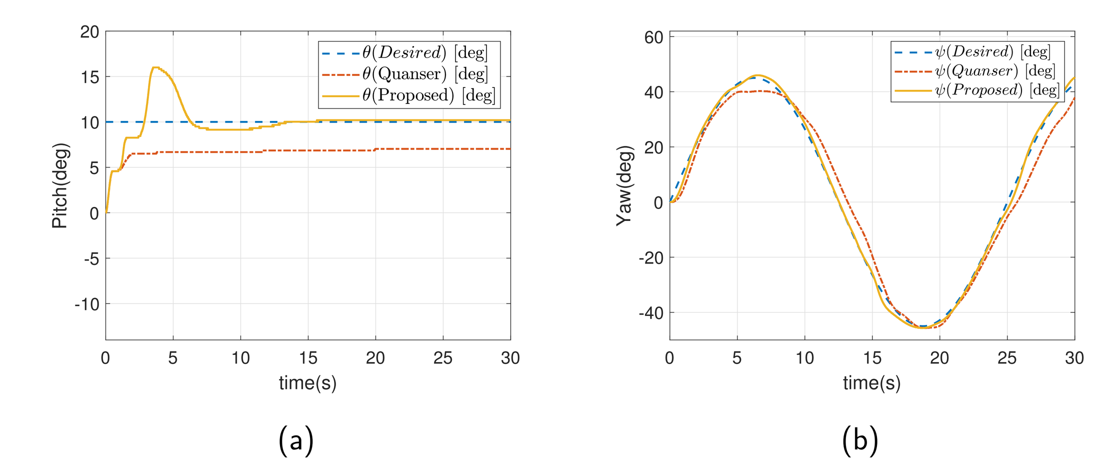

Figure 9: Comparison between P and PI control for a step input is shown for (a) the main rotor and (b) the tail rotor

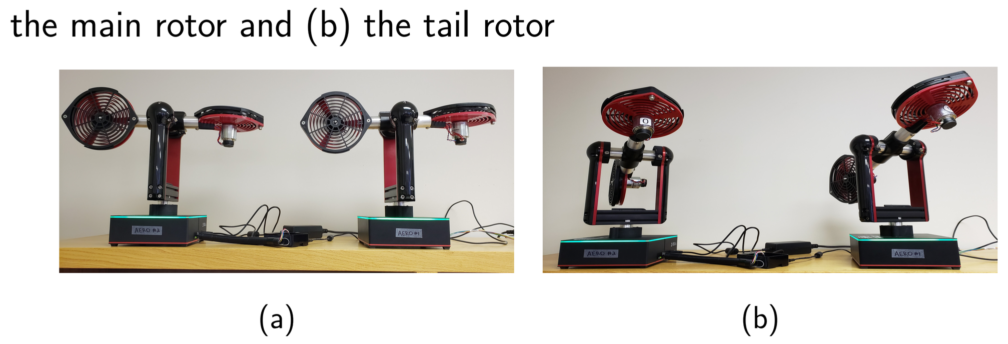

Figure 10: (a) Time = 0 and (b) Time = 10

Conclusion and Future Work

- Model-based reinforcement learning technique (ADP) is useful when system model is unknown
- Implement PI controller for ADP algorithm
- Use digital compass to increase accuracy of orientation and help identify initial position