

# 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

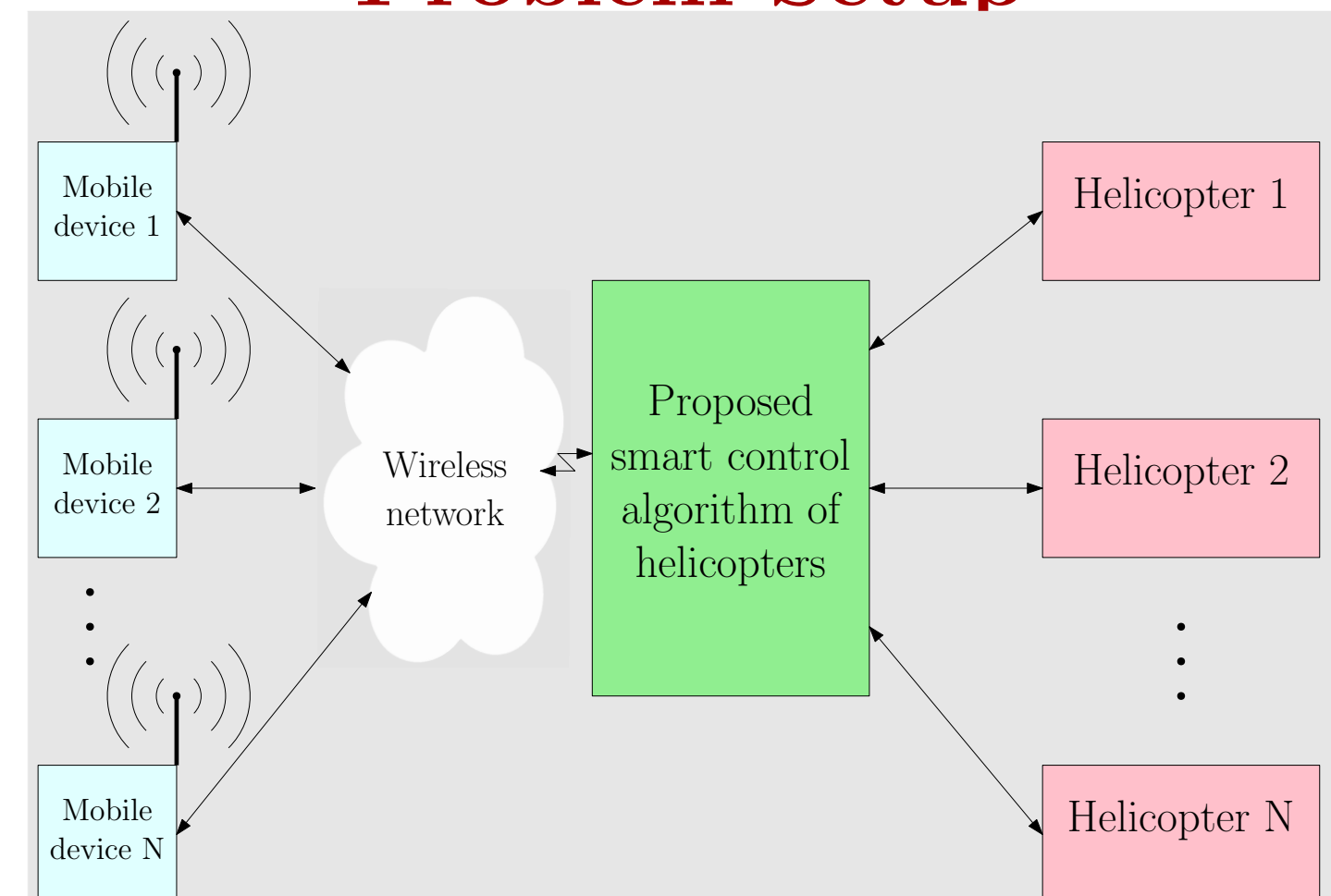


Figure 1: High level architecture of the proposed system.

## Motion (Trajectory) Control Algorithm

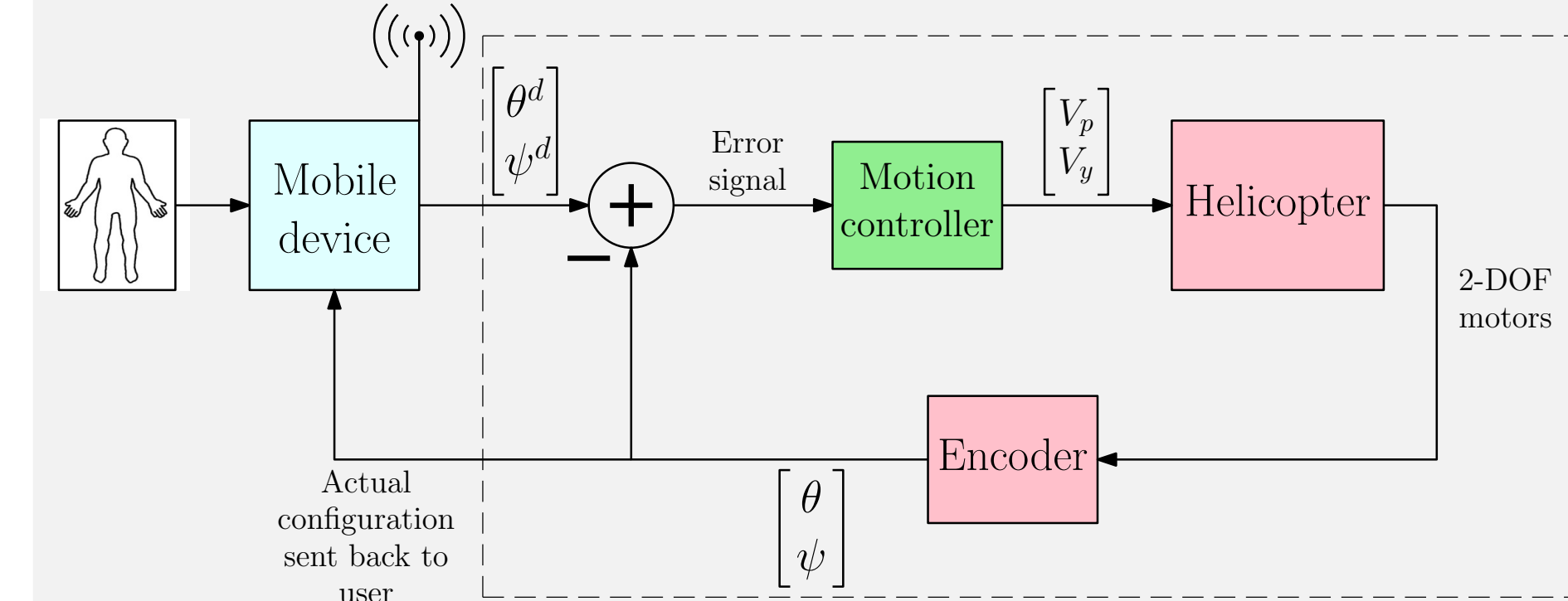


Figure 3: A desired orientation is given by a user. The difference between this input and the actual position is calculated. The controller calculates the proper amount of voltage to apply to the DC motors.

- Employ state-space representation of 2-DOF helicopter:

$$\dot{\mathbf{x}} = \mathbf{A}\mathbf{x} + \mathbf{B}\mathbf{u}$$

- Use state feedback law  $\mathbf{u} = -\mathbf{K}\mathbf{x}$  to minimize the quadratic cost function:

$$J(\mathbf{u}) = \int_0^{\infty} (\mathbf{x}^T \mathbf{Q} \mathbf{x} + \mathbf{u}^T \mathbf{R} \mathbf{u} + 2\mathbf{x}^T \mathbf{N} \mathbf{u}) dt$$

- Find the solution  $\mathbf{S}$  to the Riccati equation

$$\mathbf{A}^T \mathbf{S} + \mathbf{S} \mathbf{A} - (\mathbf{S} \mathbf{B} + \mathbf{N}) \mathbf{R}^{-1} (\mathbf{B}^T \mathbf{S} + \mathbf{N}^T) + \mathbf{Q} = 0$$

- 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

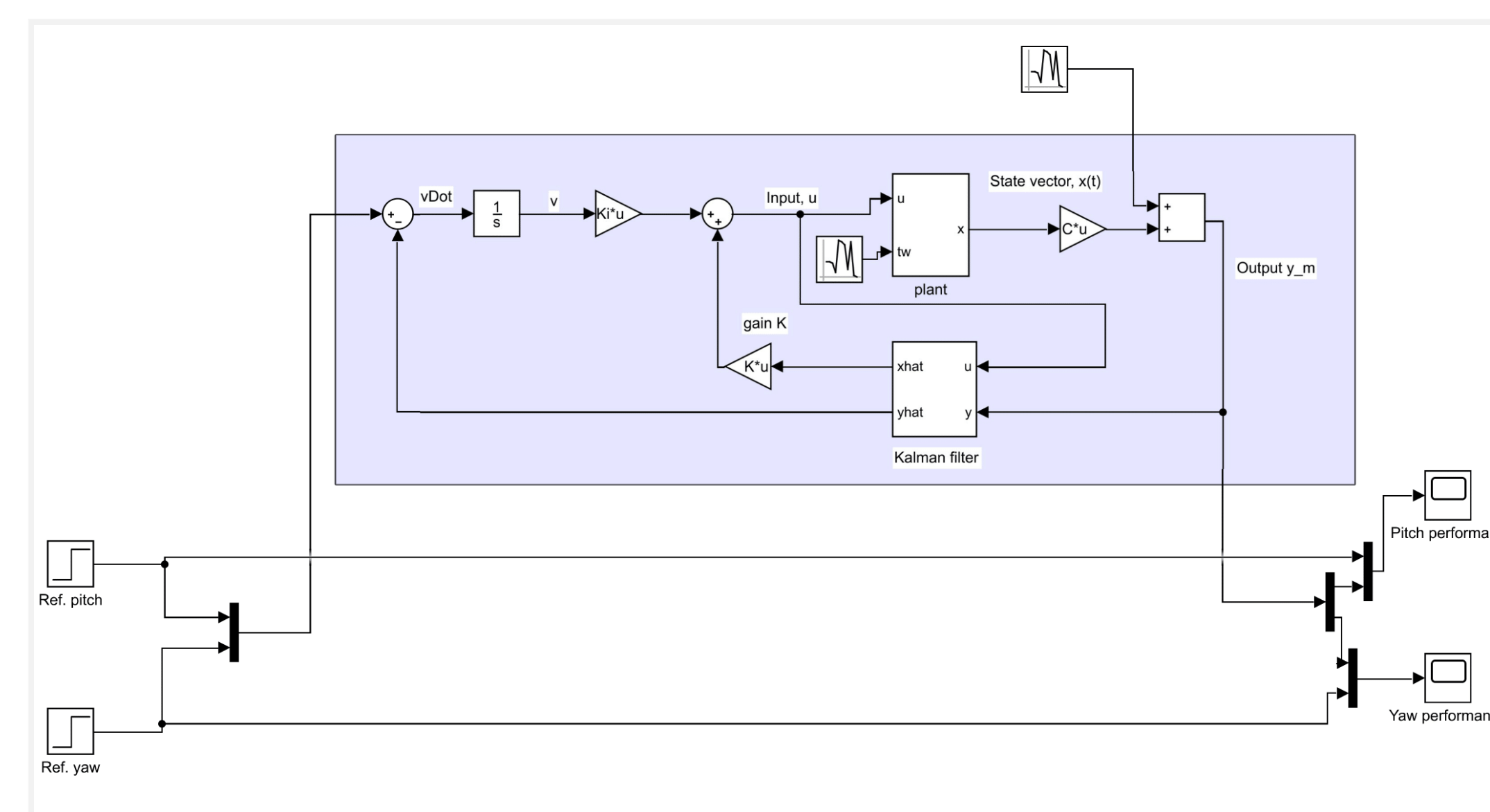


Figure 4: Noise resistant 2-DOF helicopter model.

## Reinforcement Learning Algorithm

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

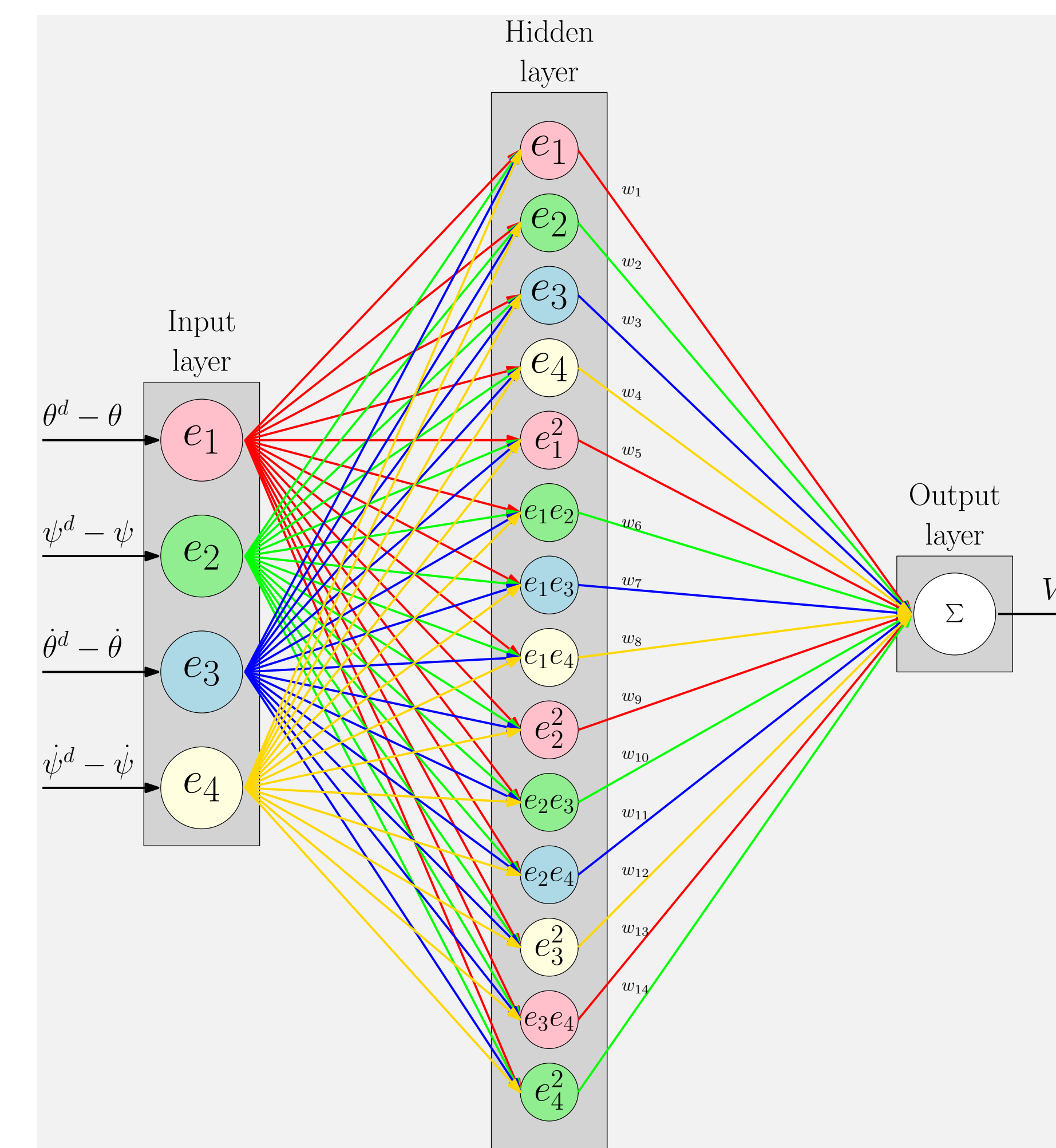


Figure 5: ADP Neural Network

## Simulation Results

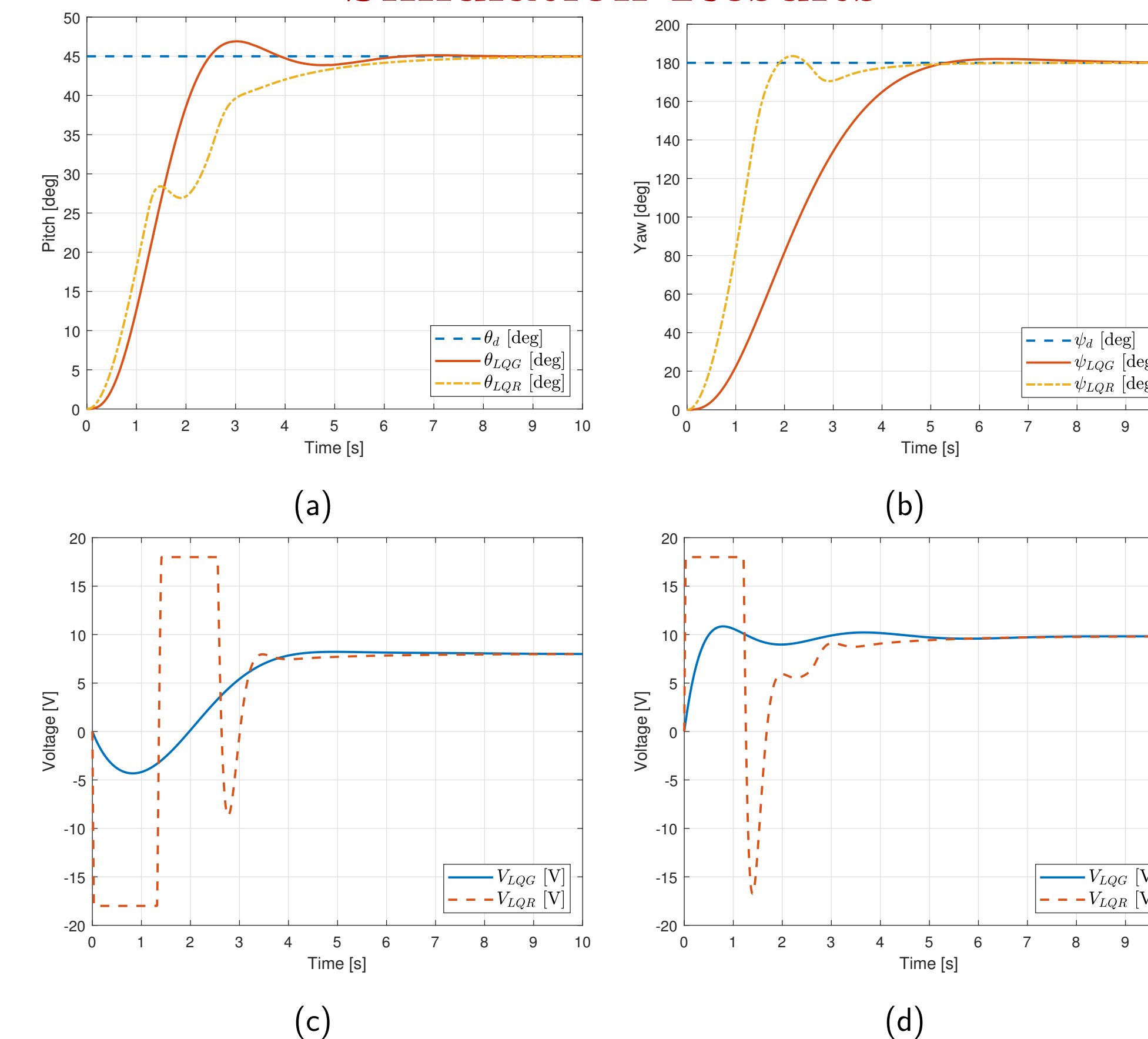


Figure 6: A comparison between LQG and LQR control for a step input is shown for (a) the main rotor and (b) the tail rotor and the corresponding voltages in (c) and (d)

## Experimental Results

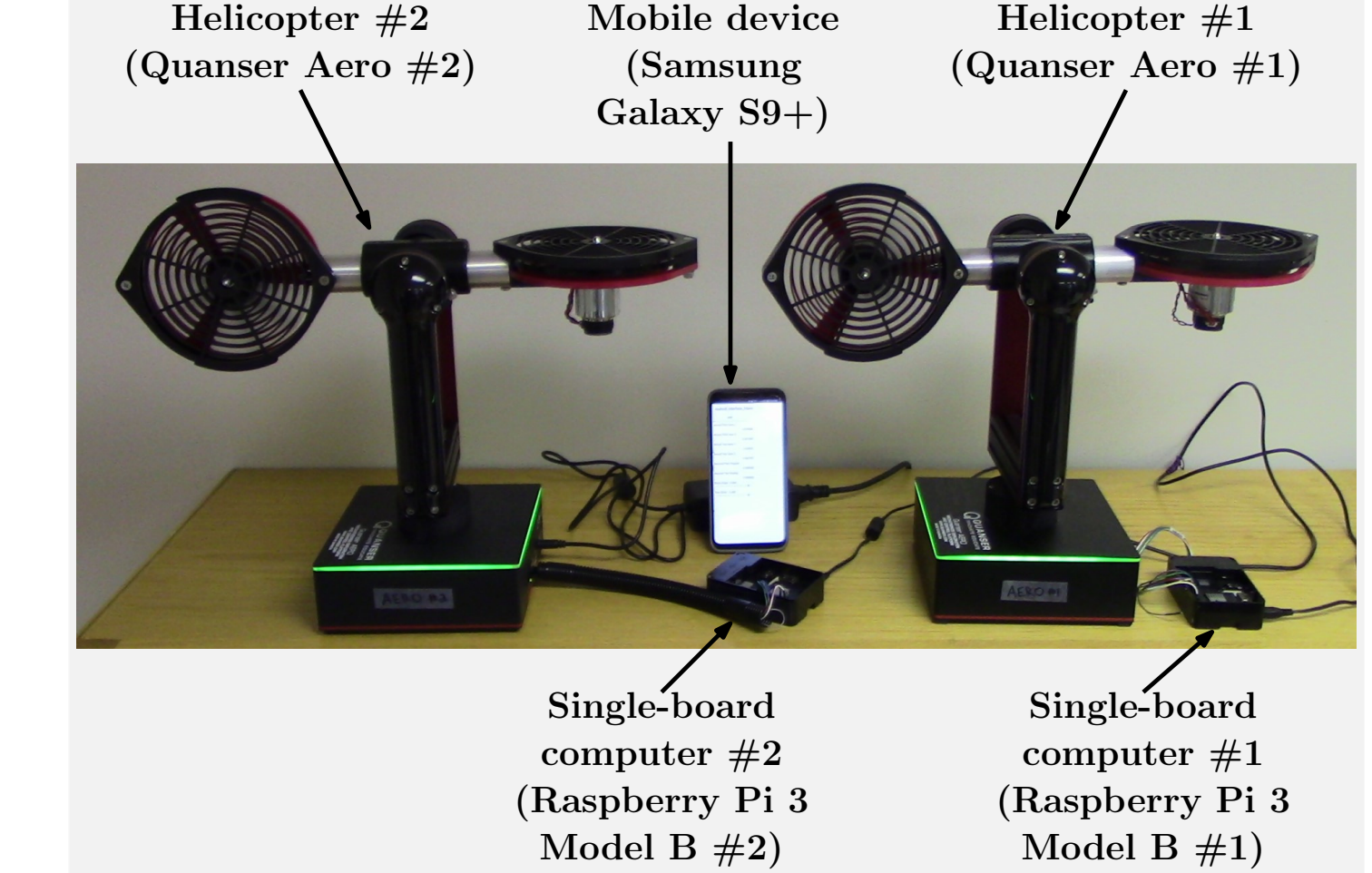


Figure 7: Experimental Setup

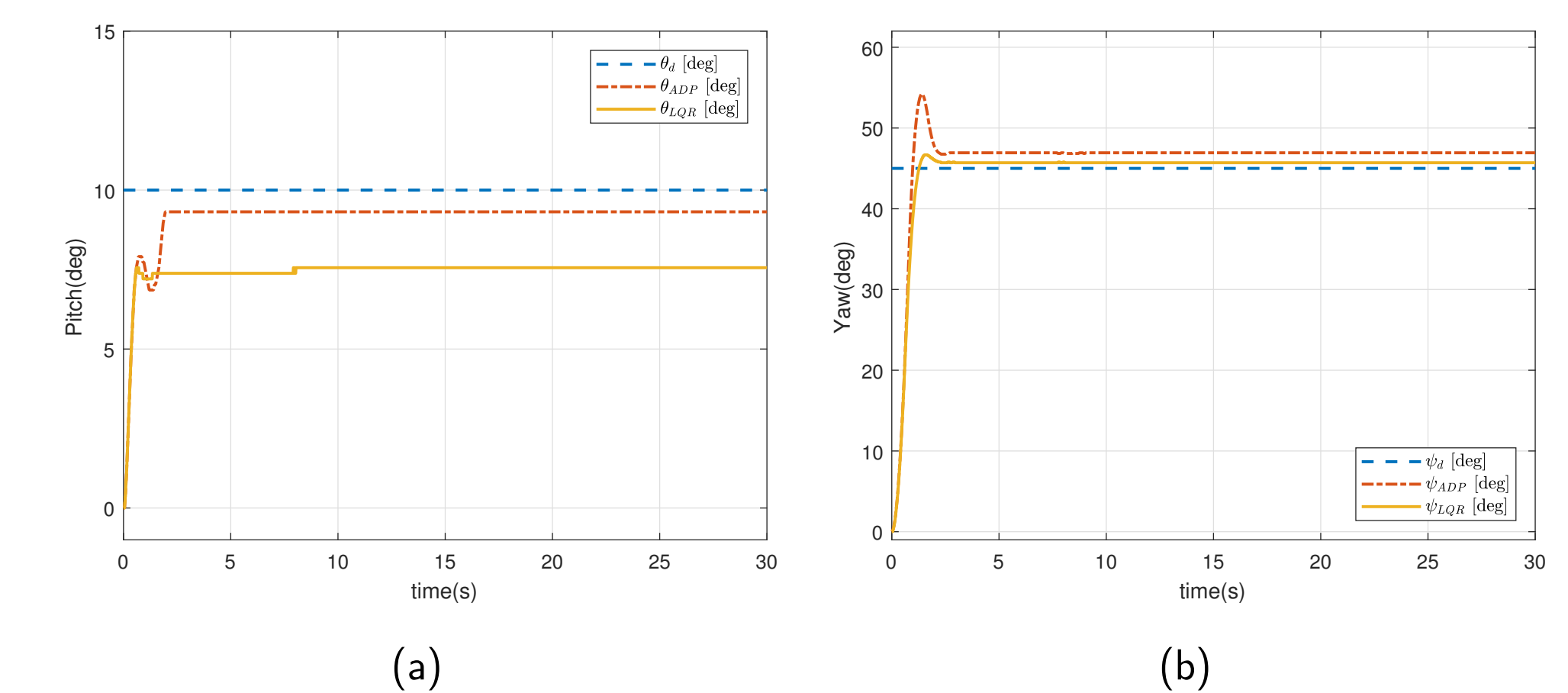


Figure 8: ADP experimental results for (a) the main rotor and (b) the tail rotor given a step input

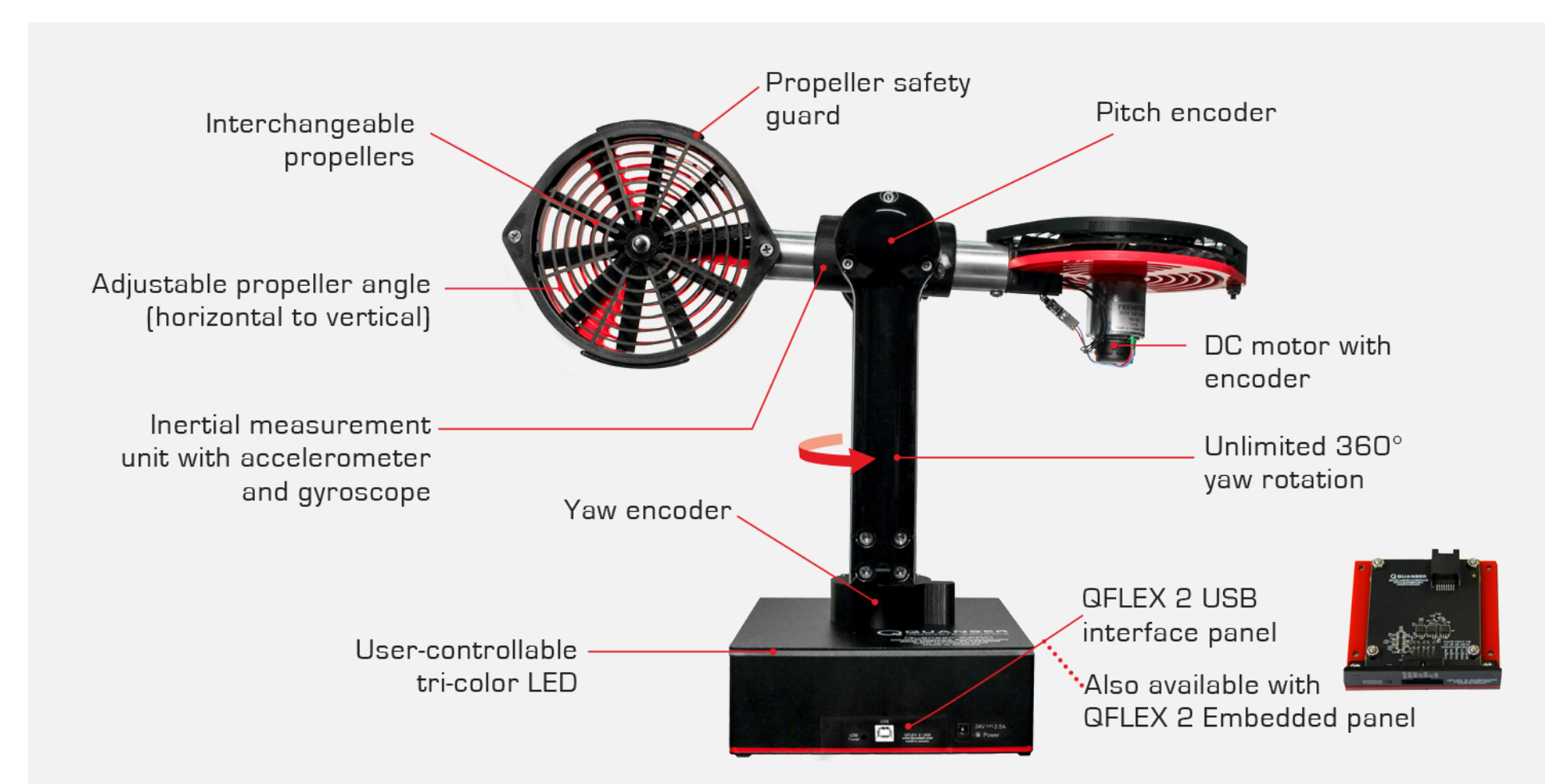


Figure 2: 2-DOF helicopter (Quanser Aero).

- State-space representation of 2-DOF helicopter

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

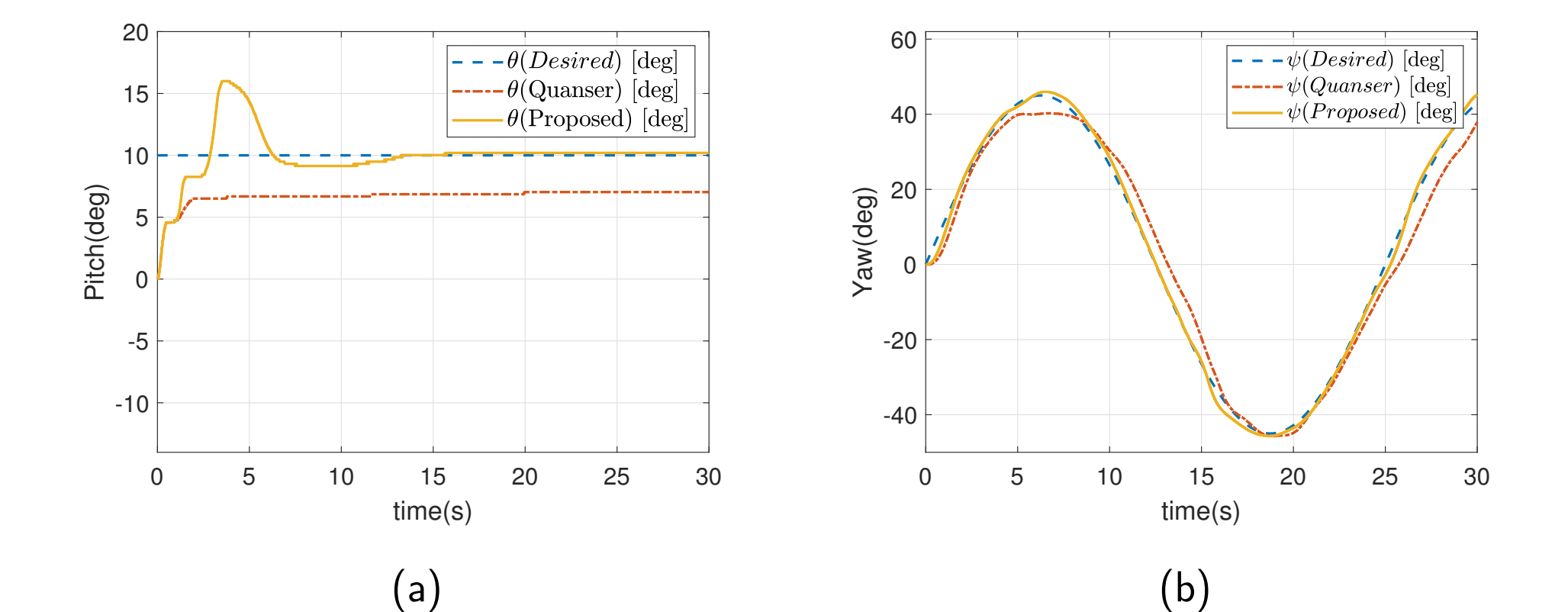


Figure 9: Comparison between P and PI control for a step input is shown for (a) the main rotor and (b) the tail rotor



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