Smart Control Algorithm for 2-DOF Helicopter

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Outline

1. Introduction
2. Background Study
   - Control Techniques
   - Modeling a 2-DOF Helicopter
   - Prior Work
3. Subsystem Level Functional Requirements
   - Block Diagram
4. Preliminary Work
   - LQR Simulation
   - LQR via USB
   - LQR via Wireless
   - Demonstration
5. Parts List
6. Schedule for Completion
7. Future Directions

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Introduction

- Helicopter are important for short-distance travel
  - air-sea rescue
  - fire fighting
  - traffic control
  - tourism
- Purpose of control system
  - resistance to turbulence
  - enable use of mobile device
- Which is better?
  - Fundamental (LQR)
  - Noise Filtering (LQG)
  - Machine Learning (ADP)

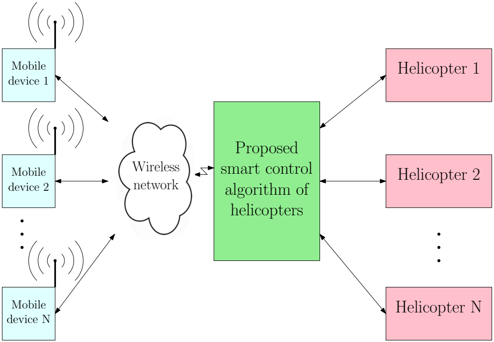

Figure 1: General High-Level System Architecture

Introduction

- This project will:
  - use a pair of 2-DOF (2-degrees-of-freedom) testing platforms
  - implement control algorithms on embedded system
  - use mobile device for user control
  - encourage research
  - serve as an educational tool

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Various control techniques have been proposed for 2-DOF helicopters such as:

- Sliding mode control [1]
- Fuzzy Logic control [2] [3] [4]
- Data-driven Adaptive Optimal Output-feedback control [5]
- Decentralized discrete-time neural control [6]

These control techniques employ advanced mathematics that are difficult to implement on embedded systems.

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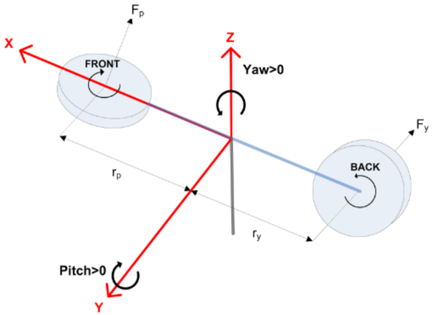

Figure 2: Model of a 2-DOF Helicopter

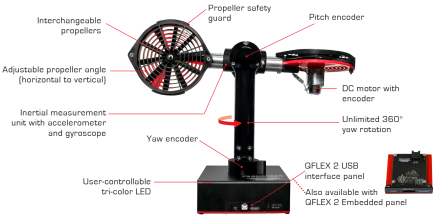

Figure 3: Quanser Aero

- Characterized by fixed base
  - Can change 2 of 3 possible orientations...
    - Pitch (θ)
    - Yaw (ψ)
    - *Not Roll*
  - and cannot change position
    - x direction
    - y direction
    - z direction

- Motors are attached to the propellers to create thrust due to air resistance
  - Main - changes pitch angle
  - Tail - changes yaw angle
- Torque due to rotation also creates a force on opposite axes

$$\dot{\mathbf{x}}(t) = \mathbf{A}\mathbf{x}(t) + \mathbf{B}\mathbf{u}(t), \text{ where} \tag{1}$$

$$\mathbf{A} = \begin{bmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ -\frac{K_{sp}}{J_p} & 0 & -\frac{D_p}{J_p} & 0 \\ 0 & 0 & 0 & -\frac{D_y}{J_y} \end{bmatrix} \text{ and } \mathbf{B} = \begin{bmatrix} 0 & 0 \\ 0 & 0 \\ \frac{K_{pp}}{J_p} & \frac{K_{py}}{J_p} \\ \frac{K_{yp}}{J_y} & \frac{K_{yy}}{J_y} \end{bmatrix},$$

- K_{sp} - being the stiffness of the axes
- K_{pp} - pitch motor thrust constant
- K_{py} - thrust constant acting on the pitch angle from the yaw motor
- K_{yp} - thrust constant acting on the yaw angle from the pitch motor
- K_{yy} - yaw motor thrust constant
- J_p - moment of inertia about pitch axis
- J_y - moment of inertia about yaw axis
- D_p - viscous damping of the pitch axis
- D_y - viscous damping of the yaw axis

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- extensive modeling & simulations
- implementation of two motion control algorithms (LQR & ADP)
- one helicopter

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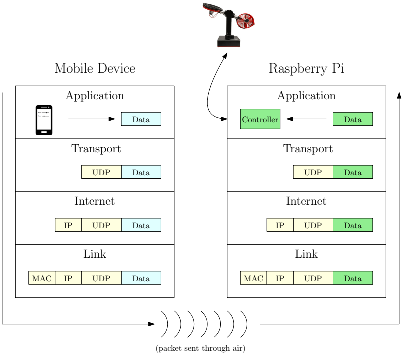

Figure 4: Communication Model

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Subsystem Level Functional Requirements

Block Diagram

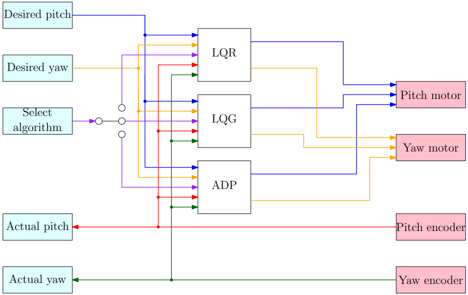

Figure 5: Low Level Smart Control Diagram

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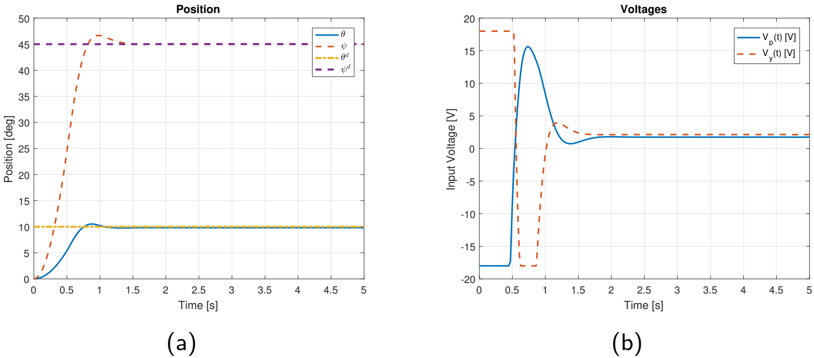

Figure 6: LQR Simulation (a) Position and (b) Voltage w/ Constant Signal

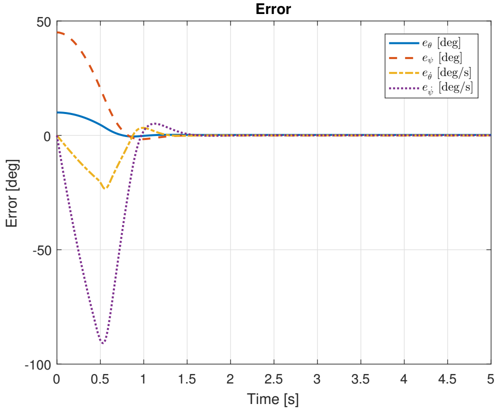

Figure 7: LQR Simulation Error w/ Constant Signal

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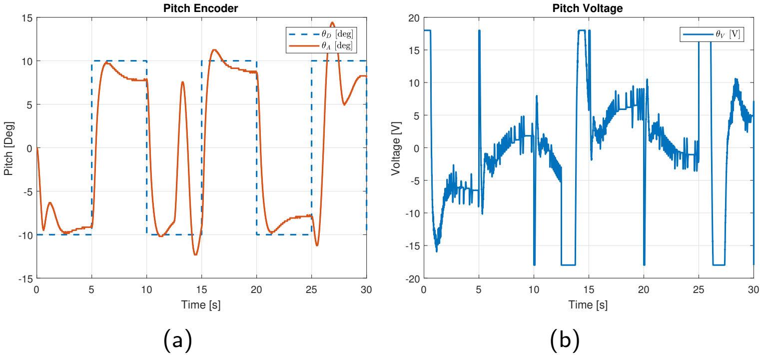
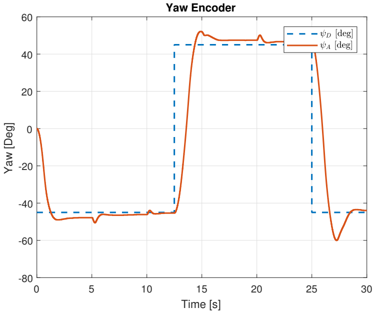
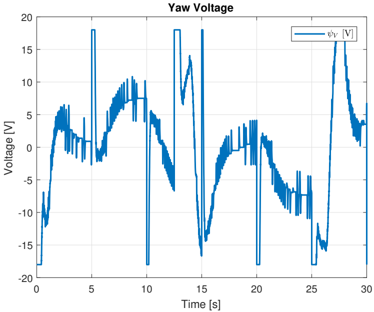


Figure 8: LQR Pitch Position (a) and Voltage (b) on PC with Square Wave Input



(a)



(b)

Figure 9: LQR Yaw Position (a) and Voltage (b) on PC with Square Wave Input

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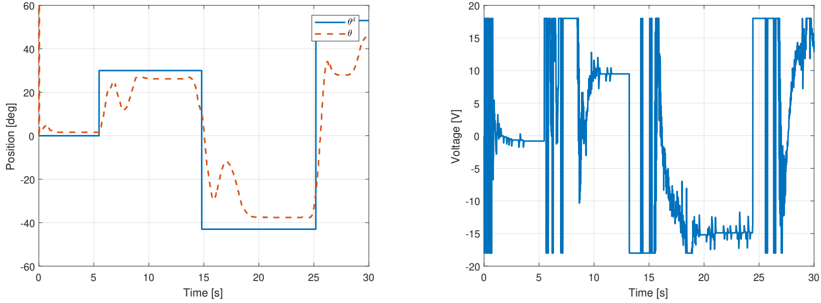
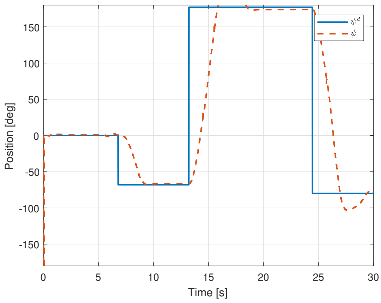
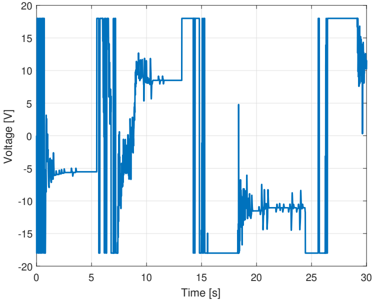


(a) (b)

Figure 10: Performance in following user's command (a) tracking pitch angle, and (b) pitch motor input voltage



(a)



(b)

Figure 11: Performance in following user's command (a) tracking yaw angle, and (b) yaw motor input voltage.

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Demonstration

Parts List

- Hardware
  - Two Quanser Aeros
    - Q-flex2 Embedded Panel
  - Two Single Board Computers (Raspberry Pi 3 Model B)
  - Android Smart-phone or Tablet
    (Note that Apple devices could also be used, however modifications are needed)
- Software
  - MATLAB & Simulink
    - Raspberry Pi Support Package
    - Android Support Package
  - Quanser Real-Time Control (QUARC)

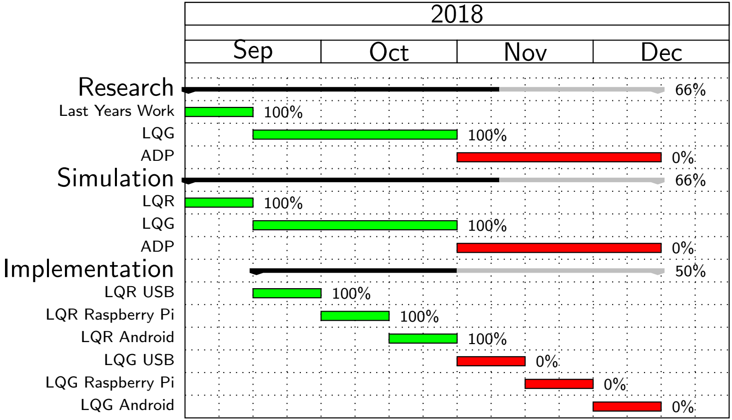

Figure 12: Gantt chart for Fall 2018

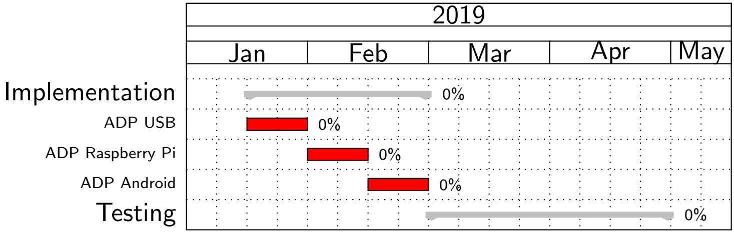

Figure 13: Gantt Chart for Spring 2019

Future Directions

- Two more motion control algorithms (LQG & ADP)
- Test plan
- Implmentation on 6-DOF Helicopter

Summary

- Embedded implementation of control algorithms
- Mobile interface

For Further Reading I

[1] S. I. K. Q. Ahmed, A.I.Bhatti, "2-sliding mode based robust control for 2-dof helicopter," *11th International Workshop on Variable Structure Systems*, June 2010.

[2] W. Chang, J. Moon, and H. Lee, "Fuzzy model-based output-tracking control for 2 degree-of-freedom helicopter," *Journal of Electrical Engineering Technology*, vol. 12.00, no. 1, pp. 1921–1928, 2017, quanser product(s): 2 DOF Helicopter. [Online]. Available: http://www.jeet.or.kr/LTKPSWeb/uploadfiles/be/201705/290520170957344003750.pdf

[3] E. Kayacan and M. Khanesar, "Recurrent interval type-2 fuzzy control of 2-dof helicopter with finite time training algorithm," in *IFAC-PapersOnLine*, July 2016, pp. 293–299.

For Further Reading II

[4] H. B.-P. P. Mndez-Monroy, "Fuzzy control with estimated variable sampling period for non-linear networked control systems: 2-dof helicopter as case study," *Transactions of the Institute of Measurement*, vol. no. 7, October 2012.

[5] W. Gao and Z.-P. Jiang, "Data-driven adaptive optimal output-feedback control of a 2-dof helicopter," in *American Control Conference*, Boston Marriott Copley Place, Boston, MA, USA, July 2016.

[6] M. Hernandez-Gonzalez, A. Alanis, and E. Hernandez-Vargas, "Decentralized discrete-time neural control for a quanser 2-dof helicopter," *Applied Soft Computing*, 2012.