

Smart Control Algorithm for 2-DOF Helicopter

Glenn Janiak Kenneth Vonckx Advisor: Dr. Suruz Miah

Department of Electrical and Computer Engineering
Bradley University
1501 W. Bradley Avenue
Peoria, IL, 61625, USA

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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 Simulation
 - LQR Simulation
 - LQG Simulation
- 5 Implementation
 - USB
 - Android
 - Demonstration
- 6 Future Directions

- 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)

Introduction

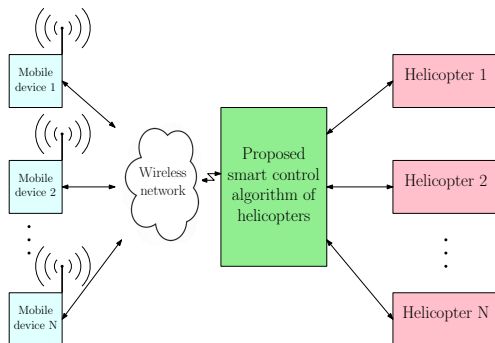


Figure 1: General High-Level System Architecture

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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Background Study

Control Techniques

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

- Sliding mode control [?]
- Fuzzy Logic control [?] [?] [?]
- Data-driven Adaptive Optimal Output-feedback control [?]
- Decentralized discrete-time neural control [?]

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

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Background Study

Modeling a 2-DOF Helicopter

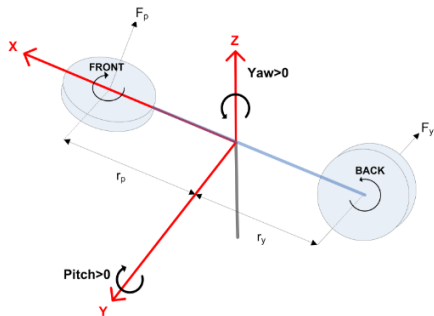


Figure 2: Model of a 2-DOF Helicopter

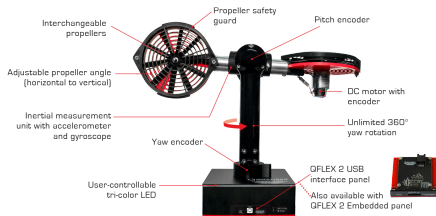


Figure 3: Quanser Aero

Background Study

Modeling a 2-DOF Helicopter

- 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

Background Study

Modeling a 2-DOF Helicopter

- 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

Background Study

Modeling a 2-DOF Helicopter

Due to the efficiency of the Quanser Aero, we can create a linearized system model:

$$\dot{\mathbf{x}}(t) = \mathbf{A}\mathbf{x}(t) + \mathbf{B}\mathbf{u}(t), \text{ such that} \quad (1)$$

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

Background Study

Modeling a 2-DOF Helicopter

- 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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Prior Work

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

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Subsystem Level Functional Requirements

Block Diagram

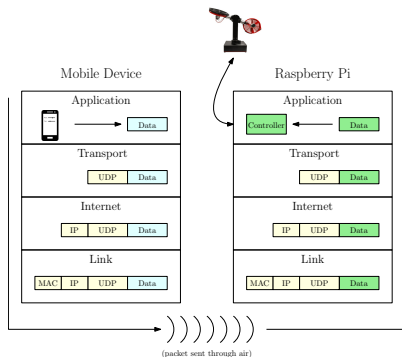


Figure 4: Communication Model

Subsystem Level Functional Requirements

Block Diagram

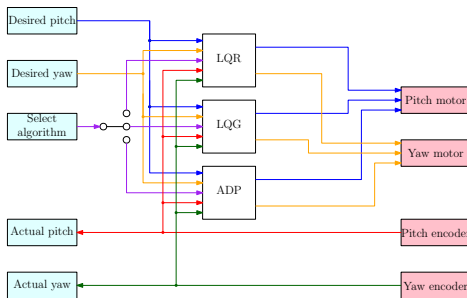


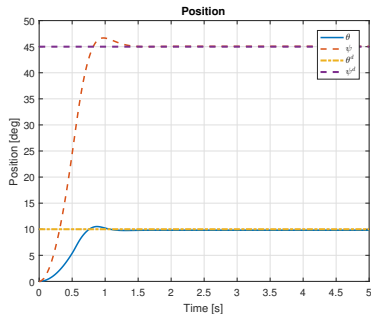
Figure 5: Low Level Smart Control Diagram

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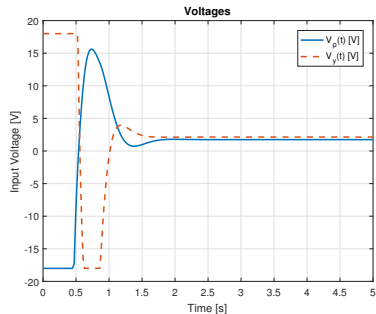
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Simulation

LQR Simulation (P Controller)



(a)



(b)

Figure 6: LQR Simulation (a) Position and (b) Voltage w/ Step Input

Simulation

LQR Simulation (P Controller)

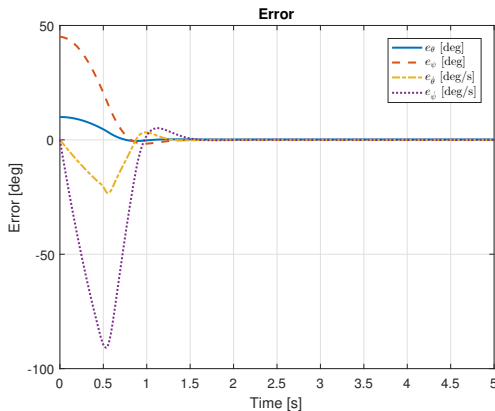
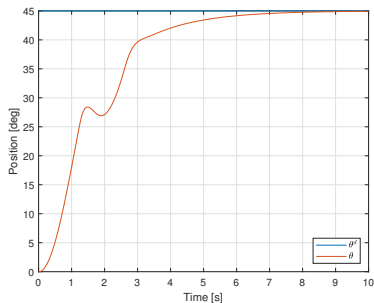


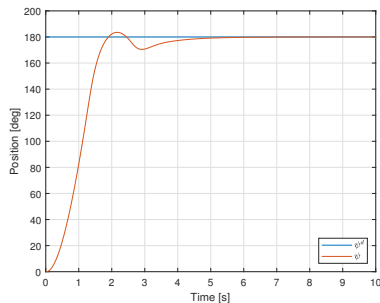
Figure 7: LQR Simulation Error w/ Constant Signal

Simulation

LQR Simulation (PI Controller)



(a)

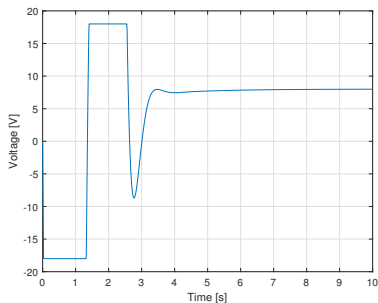


(b)

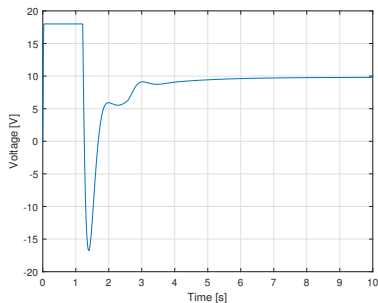
Figure 8: LQR Simulation (PI Controller) (a) Pitch Position and (b) Yaw Position w/ Step Input

Simulation

LQR Simulation (PI Controller)



(a)



(b)

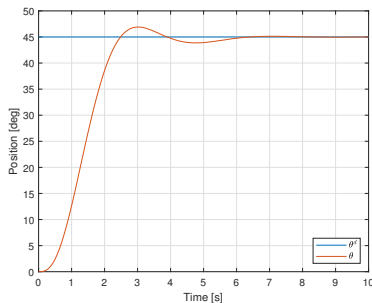
Figure 9: LQR Simulation (PI Controller) (a) Pitch Voltage and (b) Yaw Voltage w/ Step Input

Outline

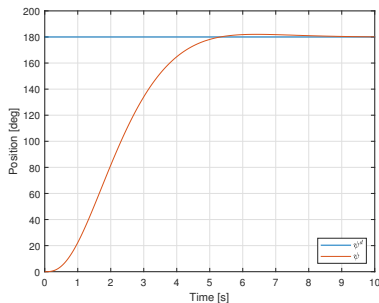
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Simulation

LQG Simulation (PI Controller)



(a)

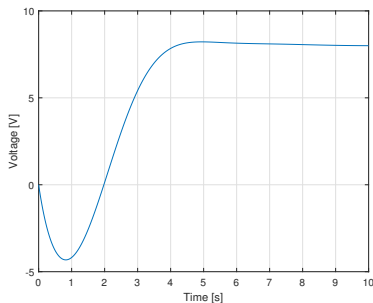


(b)

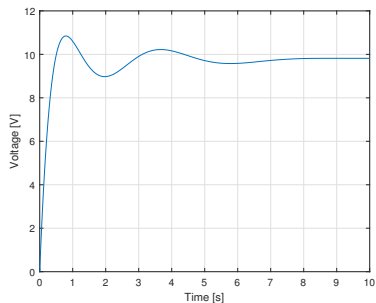
Figure 10: LQG Simulation (PI Controller) (a) Pitch Position and (b) Yaw Position w/ Step Input

Simulation

LQG Simulation (PI Controller)



(a)



(b)

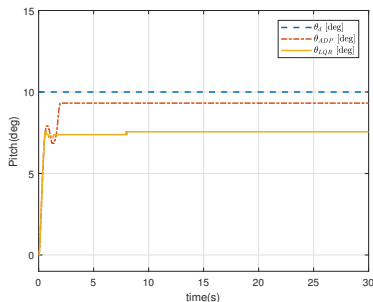
Figure 11: LQR Simulation (PI Controller) (a) Pitch Voltage and (b) Yaw Voltage w/ Step Input

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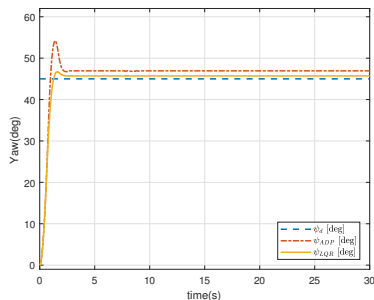
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Implementation

ADP and LQR (P Controller) USB



(a)



(b)

Figure 12: USB Implementation comparison between ADP and LQR (P) for (a) Pitch and (b) Yaw orientations w/ Step Input

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Implementation

Android

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Demonstration



Future Directions

- Discretization of System
- Digital Compass
- Enhanced Smart Control

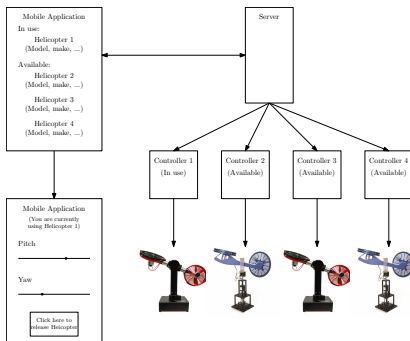


Figure 13: Enhanced Smart Control

- Implementation on 6-DOF Helicopter

Summary

- Embedded implementation of control algorithms
- Mobile interface
- PI control improves steady-state error
- ADP is best when system parameters are unknown or time-variant
- Add table for RMSE?

For Further Reading I