Specialization Project

Andreas Larsen

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Student name: Andreas Larsen

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Title: Approaches To Real-Time Simulation of Aircraft Autopilot Software

Project description:

A study of state-of-the-art methods for simulating the physical behavior of aircrafts and for developing autopilot control logic. The purpose is to identify best-practice approaches to develop said simulator that can function as a benchmark for autopilot software performance. The conclusion of the project is a set of recommended methods and approaches for implementing the software and concerns for deploying the autopilot on real world aircrafts.

Abstract

TODO Fill out

Preface

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Introduction (2-5p)

1.1 Purpose

1.2 Motivation

1.3 Context

1.4 Intended Audience

1.5 Overview

Chapter 2

Methods of Aircraft Simulation (18p)

2.1 Physics and Models 14p

2.1.1 Aerodynamics 9p

- Generally about the most important principles in aerodynamics.

2.1.1.1 Drag 1p

- How does air resistance work and how does it affect aircrafts?
- Different types of drag with different properties (parasitic, lift-induced, wave)

2.1.1.2 Lift 1p

- What causes lift and how is heavier-than-air flight possible?

2.1.1.3 Turbulence 1p

- Laminar and turbulent flows
- Reynolds number

2.1.1.4 Shockwaves 1p

- Speed of sound
- The Mach barrier

2.1.1.5 Fixed-wing: Airplanes 2p

- General description
- Lift and drag
- Maneuverability
- Supersonic flight

2.1.1.6 Rotary-wing: Helicopters 2p

- General description
- Lift and drag
- Maneuverability
- Main rotor torque compensation 0.5p
  - Counter-rotation
  - Tail rotor
- Rotor aerodynamics 1.5p
  - Reynolds number and Mach number effects [2, p.350]
  - Dynamic stall [2, p.525]
  - Blade tip vortices [2, p.567]
- Ground effect [2, figures at p.261] 0.5p

2.1.2 Computational Methods for Aerodynamics 5p

- Relevant info[2, p.771] 1p

2.1.2.1 Fluid Mechanics Equations 2p

Navier-Stokes Equations

Euler Equations

Etc..

2.1.2.2 Numerical Modelling Methods 2p

CFD

Finite Element

Others..?

2.2 Real-Time and Simulation-Time 4p

- How does real-time constraints differ from simulation-time?
- Parallel computing

2.2.1 Simulation Depth 1p

- Dimensional (1D, 2D, 3D)
- Quantities (particle systems, grids)
- Complexity (mesh details, physics model relations and constraints)

2.2.2 Stiffness and Time Steps 2p

- Particle dynamics
- Numerical stiffness vs. time steps required
  - Springs, positions and velocities
- Implicit methods
- Constrained dynamics

Chapter 3

Methods of Autopilot Control (18p)

3.1 Control Theory and Basic Concepts 1p

3.1.1 Direct Digital Control 1p

3.2 Modern Control 9p

3.2.1 PID loops 8p

- Basic PID loop functionality
- Combinations P, I, PD, PI and PID

3.2.1.1 Closed and open loops 0.5p

Summarising these properties we can define:

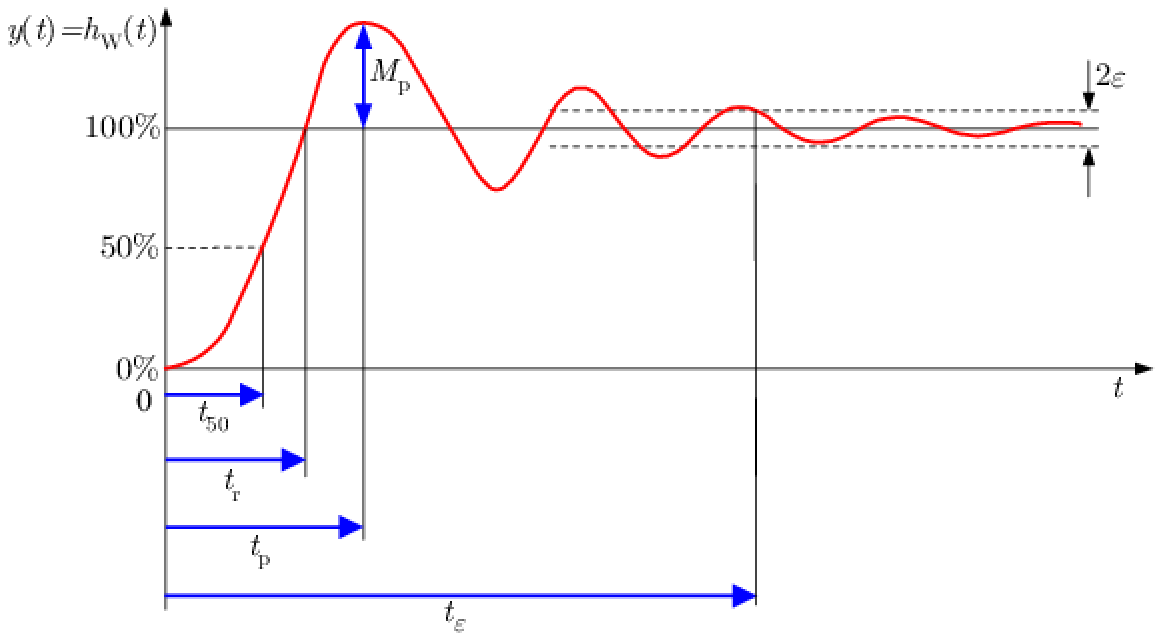
Systems in which the output quantity has no effect upon the process input quantity are called open-loop control systems.
Systems in which the output has an effect upon the process input quantity in such a manner as to maintain the desired output value are called closed-loop control systems.

http://www.atp.ruhr-uni-bochum.de/rt1/syscontrol/node4.html

3.2.1.2 Performance Indices 3p

Time-Response

Maximum overshoot, peak time, rise time, settling time etc..



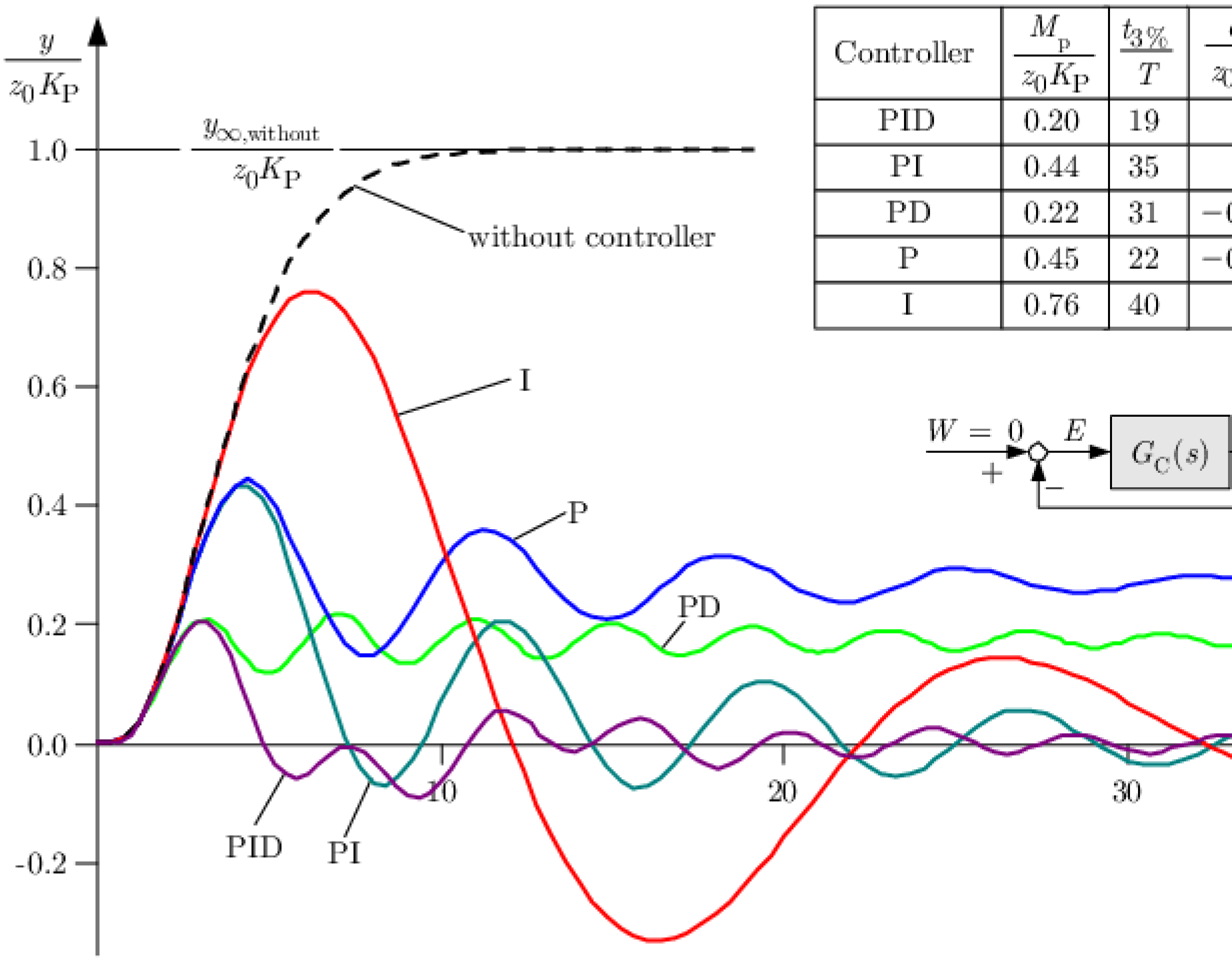
http://www.atp.ruhr-uni-bochum.de/rt1/syscontrol/node57.html

Integral Error

Table 7.2: The most common integral performance indices
http://www.atp.ruhr-uni-bochum.de/rt1/syscontrol/node58.html

3.2.1.3 Performance Tuning 4p

Optimal PID tuning
http://www.atp.ruhr-uni-bochum.de/rt1/syscontrol/node62.html
Comparison of configurations P, I, and D



Controller	$\frac{M_p}{z_0 K_P}$	$\frac{t_{3\%}}{T}$
PID	0.20	19
PI	0.44	35
PD	0.22	31
P	0.45	22
I	0.76	40

http://www.atp.ruhr-uni-bochum.de/rt1/syscontrol/node63.html

Trial and Error 1p

Ziegler-Nichols Method 1p

Root Locus Method 1p http://www.atp.ruhr-uni-bochum.de/rt1/syscontrol/node69.html (root locus)
http://www.cds.caltech.edu/~murray/courses/cds110/fa02/cds101/lectures/L9.1_pid+rlocus_file
+ root locus slides)

- Degree of Stability in Closed Loop
- Very useful in control design to measure performance

3.2.2 Auto Regressive Model 1p

3.3 Kalman Filter 5p

- Similar to Hidden Markov Model but differs in
  - Continuous hidden state variables (not discrete)
  - Only one distribution supported, namely Gaussian
- Recursive estimator
- Current estimate = Previous estimate + current measure
  - $\mathbf{x}_\mathrm{k} = \mathbf{F}_\mathrm{k}\mathbf{x}_\mathrm{k\text{-}1} + \mathbf{B}_\mathrm{k}\mathbf{u}_\mathrm{k} + \mathbf{w}_\mathrm{k}$
- Current measure
  - $\mathbf{z}_\mathrm{k} = \mathbf{H}_\mathrm{k}\mathbf{z}_\mathrm{k} + \mathbf{v}_\mathrm{k}$
- $\mathbf{F}_\mathrm{k}$ = state transition model applied to previous state
- $\mathbf{B}_\mathrm{k}$= control-input model applied to the control vector $\mathbf{u}_\mathrm{k}$
- $\mathbf{H}_\mathrm{k}$= observation model that maps true state space into observed space
- $\mathbf{w}_\mathrm{k}$= process noise ˜ N(0, $\mathbf{Q}_\mathrm{k}$)
- $\mathbf{v}_\mathrm{k}$= observation noise ˜ N(0, $\mathbf{R}_\mathrm{k}$)

3.3.1 Linear-Quadratic-Gaussian Control problem

- Linear-quadratic regulator (LQR)
- Linear-quadratic-Gaussian controller

3.4 Deployment Issues 3p (skippable)

3.4.1 Hardware Limitations 1.5p

3.4.1.1 Performance

3.4.1.2 Power Usage

3.4.2 Safety 1.5p

3.4.2.1 Logic Robustness

3.4.2.2 Fail-safe Routines

Chapter 4

Discussion of Best-Practice Approach to Real-Time Aircraft Simulation (5p)

- Full-scale vs. mini-scale aircrafts
- Approaches and methods available
- Pros and cons for this scenario
- More..?

Chapter 5

Conclusion (1p)

- Concrete methods suited for implementation
- Reusability of this research
- Deploying

Bibliography

[1] George Done A.R.S. Bramwell and David Balmford. *Principles of Helicopter Aerodynamics*. Butterworth-Heinemann, second edition, 2001.

[2] J. Gordon Leishman. *Principles of Helicopter Aerodynamics*. Cambridge University Press, second edition, 2006.

[3] John Watkinson. *The Art of the Helicopter*. Elsevier Butterworth-Heinemann, 2004.

Appendices