ROB310 Mathematics for Robotics

Overview of the Topics Covered

Objective

This document provides an overview of the topics covered in class and related reading material.

References

The reading list refers to the following books and online content:

[1] Kreyszig, Erwin, "Advanced engineering mathematics," Wiley, 2011. [pdf]

[2] Siegwart, Roland, Nourbakhsh, Illah Reza and Scaramuzza, Davide, "Introduction to autonomous mobile robots," MIT press, 2011. [pdf]

[3] Aström, Karl J., and Wittenmark, Björn, "Computer-controlled systems: theory and design," Courier Corporation, 2013. [online]

[4] Solomon, Justin, "Numerical algorithms: methods for computer vision, machine learning, and graphics," CRC Press, 2015. [pdf] [uploaded on Quercus as Reference 1]

[5] Ratliff, Nathan, "Linear algebra: lecture notes," 2014. [uploaded on Quercus as Reference 2]

[6] Pishro-Nik, Hossein, "Introduction to probability, statistics, and random processes," Kappa Research, LLC, 2014. [online]

[7] Haug, A. J., "A tutorial on Bayesian estimation and tracking techniques applicable to nonlinear and non-Gaussian processes." MITRE Corporation, McLean, 2005. [pdf]

Course Topics

An outline of the topics covered in this course is provided below. The left column shows the lecture number.

#	Topic	Reading
1	**Introduction and Motivation**	[2], pp. 1-10
2	**System Models** Discrete-time and continuous-time systems, exact discretization for sampled systems.	[3], Ch. 2.1-2.3
3	**Numeric Methods** Sources of numeric error, numeric stability.	[4], Ch. 2.1-2.2
4	**Numeric Methods for Root Finding** Bisection, fixed-point iteration, Newton's method, secant method.	[4], Ch. 8.1-8.2
5	**Numerical Integration and Differentiation** Integration methods (midpoint, trapezoidal and Simpson's rule), differentiation methods (forward, backward and centered difference).	[4], Ch. 14
6	**Ordinary Differential Equations (ODEs)** Time-stepping methods (Euler forward, Euler backward), numerical properties (explicit vs. implicit methods, accuracy: localized and global truncation error, numerical stability).	[4], Ch. 15.1-15.3.2

7	**Ordinary Differential Equations (ODEs)** Time-stepping methods (trapezoidal, Runge-Kutta), multi-step methods (midpoint, Adams-Bashforth), consistence of ODE methods.	[4], Ch. 15.3.3-15.5
8	**Simulation Parameters, Introduction to Optimization** Characteristic time constants of an ODE, rules of thumb for simulation parameters (including simulation time and step size), optimization problem definition.	[4], Ch. 9.1
9	**Unconstrained Optimization** First-order and second-order optimality conditions, convexity.	[4], Ch. 9.2
10	**Numeric Solvers for Unconstrained Optimization Problems** Newton's method and golden section search for one-dimensional problems, gradient descent and Newton's method for multivariate problems.	[4], Ch. 9.3-9.4
11	**Constrained Optimization** Equality and inequality constraints, KKT conditions, sketch of relevant optimization algorithms.	[4], Ch. 10.1-10.3
12	**Convex Optimization Problems** Characteristics of convex problems.	[4], Ch. 10.4
13	**Advanced Linear Algebra** Matrix properties (symmetric, positive (semi-)definite, condition number), vector and matrix norms, eigenvalue problem.	[4] Ch. 1.1-1.3, 4.2.1, 6.1-6.2; [5] Ch. I-II; [1] Ch. 7, 8
14	**Singular Value Decomposition** Derivation.	[4] Ch. 7.1-7.2; [5] Ch. III
15	**Singular Value Decomposition** Interpretation and applications.	[4] Ch. 7.1-7.2; [5] Ch. III
16	**Probability Review** Discrete and continuous random variables, joint probability distributions, marginalization, conditioning.	[1], Ch. 24.1-24.3, 24.5-24.6, 24.9; [6] Ch. 1-3
17	**Conditional Probability, Bayes' Theorem** Independence and conditional independence, examples for Bayes' theorem.	[6] Ch. 1-6
18	**Bayes' Theorem, Expected Value and Variance, Change of Variables** Interpretation of Bayes' theorem in terms of estimating a quantity from multiple observations, definition of expected value and variance, functions of random variables.	[6] Ch. 1-6
19	**Bayesian Tracking** Recursive estimator equations based on prior update and measurement update.	[7] (partially)
20	**Remarks on Computer Implementation of Probabilistic Approaches** Sampling an arbitrary distribution.	[6] Ch. 12
21	**Extracting Estimates from Probability Distributions** Maximum Likelihood, Maximum A Posteriori, Minimum Mean Squared Error.	[6] Ch. 9.1
22	**Gaussian Probability Density Functions** Marginalization, conditioning, summation, multiplication, passing through a nonlinearity.	[6] Ch. 4.2.3, 5.3.2
23	**Complex Numbers: A Review** Representations of complex numbers, complex conjugate, addition, subtraction, multiplication, division. *Possible extension: complex functions.*	[1] Ch. 13

Did you find a book, video or online content that was helpful and is not listed here? Please send me an email at schoellig@utias.utoronto.ca. I'd love to hear about it!