Delft University of Technology

Delft Center for Systems and Control

MSc. Systems and Control

Report on prerequisites

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Contents

1 Introduction

This document is written as a guideline for new System and Control students. We present relevant concepts that the student should be familiar with. Students from the bachelor mechanical engineering from the TU Delft have been taught these concepts in various courses. This document focuses on students from other studies and universities. However, if you want to get a head start it is wise to thoroughly scan this document. In general, all concepts fall into one of the following categories: (Linear) algebra, calculus, control theory and probability theory. We refer to a *freely available* book for each subject:

1. Linear algebra: "Introduction to Applied Linear Algebra" by Boyd [1]
2. Calculus: "Calculus" by Strang [6]
3. Control theory: "Feedback Systems: An Introduction" by Astrom and Murray [3]
4. Probability theory: "Introduction to probability" by Bertsekas [7]

Open MIT courses that have relevant lectures/chapters.

1. Dynamic systems and control "Open MIT course" by Dahle [2]
2. Linear Algebra "Open MIT course" by Strang: Lectures 3-10, 14, 21, 22, 25, 29

   Recommended by the lecturer of SC42015
3. Signals and Systems "Open MIT course" by Oppenheim with the corresponding textbook: "Signals and System" by Oppenheim [5](not freely avaiable)

Tip, Buy this book before the first quarter: "Filtering and System Identification: A Least Squares Approach" by Verhaegen and Verdult [8] is the course book for SC42025 Filtering & Identification. This course has an open book exam and you will need to buy it for the course anyway. The first chapters (1-4) provide an excellent overview of most concepts listed in this document. Always good to keep it close. **It is known amongst students as thé handbook for S&C**

1.1 Programming

Programming is an integral part of the course work within the master. It is expected the students can program in python (TUD standard). However, Matlab is the most used (programming) language used within S&C. Most courses use Matlab as a computing and visualisation tool. The focus within in SC is on computing, not on (object oriented) programming. Within the course work understanding the theory behind a script is important. Nevertheless, good programming skills will help out a lot.

Sources for getting started with Matlab

1. Get Started with Matlab Matrixes and Arrays, Array Indexing, 2-D plots
2. Matlab cheat sheet + Tutorial: Vectors, Matrices and Looping
3. Control Systems Toolbox: Get familiar with the basic commands of the Control system toolbox: tft, zpk, margin etc.

Download of MATLAB is available via the TU Delft Sofware platform (login via NetID required).

Python has gained in popularity over the last decade in academia. It has become more popular within the DCSC aswell. Jupyter notebook offers a Matlab like environment and is easy to use.

1. Installation guide: Python, Anaconda, Jupyter.
2. TCLab Offers a range of sample codes in Matlab, Simulink and Python for control applications (Transfer functions, State space, ODE)

1.2 Youtube

Youtube can be great source for videos on subjects within SC. These videos are relatively short and often focus on a single subject. These series are not limited to just prerequisites and some cover the course subjects. Here we *marked* the relevant subjects for

1. Essence of Linear Algebra, Calculus and Differential Equations by 3Blue1Brown. *Great visual derivations of the theory*
2. Jordan forms by The Bright Side of Mathematics *Important concept in linear algebra*
3. Control bootcamp by Steve Brunton *Linear systems and Stability (1-3)*
4. Control System Lectures by Brain Douglas *PID Control, Bode plots, Nyquist Stability Criterion*

2 First quarter courses

The first quarter courses start of quickly after the introduction week. Your skills on linear algebra will be tested by the course work of Control Theory. The courses Statistical Signal Processing and Control Theory will require the most prerequisite knowledge.

2.1 SC42015 Control Theory

6 ECTS Control theory starts with a quick recap of the most basic knowledge of (linear) control theory. "Feedback control by Astrom and Murray"[3] is used as complementary material to the lectures. Most of these concept have been covered in the course: "WB3240 Systems and Control Engineering (Systeem and Regeltechniek)" Important material per chapter of [3]:

1. Differential equations and state space models (Ch. 2.1-2.3)
2. Equilibrium points and stability (Ch. 4.1-4.4)
3. Linearity, Matrix exponential, Input-output response, Linearization (Ch. 5.1-5.4)
4. Transfer functions Gains, Poles and Zeros, Block diagrams (Ch. 8.1-8.3)

Other material:

1. Gradients (Ch. 13.4) [6]
2. Complex numbers and poles
3. Linear Algebra Review (Ch. 1.1) [2]
4. Norms (Ch. 3.1) [1]
5. Crimes against Matrices

Most of these concept have been covered in the course: WB3240 Systems and Control Engineering. Video series on the basics concepts:

1. Linear Algebra "Open MIT course by Strang": Lectures 3-10, 14, 21, 22, 25, 29 *Recommended by the lecturer*
2. Control System Lectures: Transfer functions and Stability (5,16,17)
3. Essence of linear algebra: Eigenvalues and Eigenvectors (14,15)
4. Control bootcamp: Linear systems and Stability (1-3)

Practice Material:

1. Partitioned matrices (Ex. 1.1,1.2) [2]
2. Matrix multiplication (Ex. 10.2-10.4) [1]
3. Matrix inverses (Ex. 11.6,11.7) [1]

2.2 SC42150 Statistical Signal Processing

3 ECTS This course builds upon concepts taught in any basic course on probability theory and linear system theory. Two related main textbooks are "Introduction to Probability" by Bertsekas and Tsitsiklis [7], and "Signals and Systems" by Oppenheim and Willsky[5] Particular topics from these books that the students are expected to be well familiar with are as follows by chapter:

1. Expectation, mean and variance (Ch. 2.4) [7]
2. General random variables (Ch. 3.1,3.2) [7]
3. Conditional expectation (Ch. 4.3) [7]
4. Sum of random variable (Ch. 4.4) [7]
5. Covariance of Correlation (Ch. 4.5) [7]
6. Least squares estimation (Ch. 4.6) [7]
7. System theory and properties (Ch. 1.6, 2.3-2.4) [5]
8. Discrete Fourier Transform and properties (Ch. 3.7, 5.3-5.5) [5]
9. Z-transforms and properties (Ch. 10.2-10.5)[5]

Other subjects:

1. Polar coordinates (Ch. 9.1-9.2) [6]
2. Complex numbers (Ch. 9.4) [6]

Students not possession of [5] can watch the Open MIT Signals and Systems lectures on the corresponding subjects.

1. System theory (2,3)
2. Discrete-time Fourier transform (10,11)
3. Z transform (22,23)

These lectures additionally have corresponding practice sets available

2.3 SC42056 Optimisation for Systems and Control

3 ECTS An introductory course for optimisations methods within SC. Basic knowledge about (discrete-time) linear state space models and stability is required. Additionally basic programming experience with Matlab is useful (see Section 1.1) Important chapters from [3]

1. linear state space models (Ch. 2.3)
2. Stability (Ch. 4.3)

2.4 SC42155 Modelling of Dynamical Systems

3 ECTS
This is an introductory course into modelling of dynamical system. Some concepts that the student should be familiar with from [3]

1. Differential equations and state space models (Ch. 2.1-2.3)
2. Frequency domain design (Ch. 8)
3. Frequency domain analysis (Ch. 9)

3 Second quarter courses

In the second quarter courses two course start of with the design of a basic PID controller. This requires knowledge of loop shaping and PID control. Most of this is covered in [3]. An additional exercise on design PID controllers is available here (insert link to document here)

3.1 SC42025 Filtering & Identification

3 ECTS

This course builds on the basis laid by SC42155 and basic knowledge of Matlab is required. A solid background in linear algebra helps. The course book [8] reviews important concepts in the first chapters. Concepts to review to get a head start per chapter from [1]

1. Matrix multiplication (Ch. 10.1)
2. QR factorisation (Ch. 10.4)
3. Matrix Inverses (Ch. 11.2)
4. Pseudo Inverses (Ch. 11.5)

Other Material:

1. The Bright Side of Mathematics: QR decomposition

3.2 SC42061 Nonlinear Systems Theory

Studyguide -

This courses introduces the theory on non linear systems. The course is mainly focused on the theory. A recap of the following concepts in calculus helps:

1. Linearity (Ch. 5.1) [3]
2. Norms (Ch. 3.1) [1]
3. Limits and continuous functions, 'if' vs 'only if' (Ch. 2.6,2.7) [6]
4. Chain rule (Ch. 4) [6]
5. Mean value Theorm (Ch. 3.8) [6]
6. Stability (Ch. 4.3) [3]

3.3 SC42145 Robust Control

3 ECTS **Studyguide** -

The course starts with a recap on background in linear systems theory and classical feedback control. Important concepts to get a head start from [3]

1. Sensitivity functions (Ch. 11.1-11.3)
2. Loop shaping (Ch. 11.4-11.5)
3. Stability margins (Ch. 9.1-9.3)

Video series on basic concepts:

1. Control bootcamp: Sensitivity and complementary sensitivity (31-35)

3.4 SC42095 Control Engineering

3 ECTS
Studyguide *SC42015, SC42000 or similar. Knowledge of classical control techniques (systematic and realistic PID design, frequency domain approaches) as well as state space theory is required.*

The students are expected to know the systematic and realistic PID design. A systemic approach to realistic PID is given in the Chapter 8 of "Control Engineering" by Keviczky [4]. This course book is however not freely avable Basic important concepts from [3]

1. Stability margins (Ch. 9.2,9.4)
2. PID (Ch. 10.1,10.2)
3. Frequency domain Design (Ch. 11)
4. Pole placement (CH. 6.2)

Video series on PID:

1. Understanding PID Control: (1-4)

References

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