

Course overview “Introduction to Dynamical Systems in Human Movement”

Lisbon, 11th to 15th of January 2021

1. General information

Title: **Introduction to Dynamical Systems in Human Movement**

Level: Master / PhD

Lecturer(s): H.J. de Poel, PhD (h.j.de.poel@umcg.nl)

Assistant professor at the Department of Human Movement

Sciences, UMCG Groningen, The Netherlands

Assistant: Luis Gomez-Jordana Martin

2. Content overview

In this course the student is introduced with the basic mathematical principles regarding the field of linear and non-linear dynamical systems, with special reference to the study of human movement (e.g., motor control). The student acquires understanding of the very basics of the underlying mathematical principles, concepts and methods and adopts this partly through model based computer simulations using Matlab/Simulink. In practical assignments with incorporated lecture-like discourse, the crash course will cover some theoretical issues (e.g., metaphysics, analytical and numerical mathematics) alongside examples/illustrations. Issues that will be studied are:

- What is a dynamical system?
- Introduction to Simulink (the simulation environment of Matlab)
- Description and analysis methods for (non-)linear systems: differential equations, phase diagram, transformations, state/phase description, fixed points, etc.
- Effects of feedback and coupling
- Non-linear systems, stability, limit cycles, noise, chaos, etc.

Note that regarding the limited time, we will solely consider continuous systems and omit to discrete systems methods.

3. Literature

The literature used in this course consist of a combination of texts. The main book we will use is:

Fuchs, A. (2013). *Nonlinear dynamics in complex systems: theory and applications for the life-, neuro- and natural sciences*. Berlin; Heidelberg: Springer.

To prepare: Check your own university's library if it has the e-book available. Otherwise borrow their hard copy.

Other required reading will be indicated during the course.

4. Objective(s)

The student acquires understanding of the *mere basics* of the mathematical principles, concepts and methods underlying the study of linear and (complex) nonlinear dynamical systems. The student can adopt these through model based computer simulations using Matlab/Simulink and can execute basic algebraic examination in this regard. Also the course aims to challenge the student towards to acquiring skills and scientific thinking at a higher level of abstraction. Besides that, programming skills (Matlab) will be trained.

Main learning outcomes:

- Acquiring acquaintance with the field of linear and non-linear dynamical systems with reference to the study of human movement
- Acquiring understanding of some of the basic underlying mathematical principles, concepts and methods.
- Understanding these principles with regard to reading such concepts and terms in (scientific) literature about these subjects.
- Understanding these principles, concepts and terms through adopting practical methods (i.e., the practical assignments are a *means* rather than a goal!)

5. Prerequisites

The course assumes and requires sufficient *a priori* basic knowledge and skills in mathematics and programming.

Mathematics: The entry level requires some acquaintance with differential equations, differentiation and integration, and basic calculus

Furthermore, basic knowledge about analysis of (movement) signals is assumed (filtering, differentiation, etc.).

Programming/coding: The student should be able to write simple scripts/programming lines, program loops (for-loop, if-loop, etc.), import/load data, build and modify data arrays (i.e., do calculations), plot data in a figure, and use the Help-function (!). Students that (think that they) do not yet have sufficient skills are emphatically requested to take proper preparations by themselves before the start of the course. Here's some info that might be helpful:

- Acquire the 'Matlab and Simulink Student Suite' (see below at point 8) and use the 'Getting Started' booklet.
- The Mathworks offers a free onramp course/tutorial on basics of Matlab, simply create an account for free: <https://nl.mathworks.com/learn/tutorials/matlab-onramp.html>.
- Matlab page with tutorials, video's and webinars:
https://nl.mathworks.com/videos/getting-started-with-matlab-101684.html?s_tid=getstart_gs_vid
- http://www.antoniahamilton.com/matlab_for_psychologists.pdf

6. Information supply

Course material and information will be made available on electronic support.

7. Methods

The course consists of five days of computer assignments with incorporated lecture-like discourse. Students are expected to prepare for each class by reading the required literature (see point 10).

The structure of the classes will be as follows: The lecturer introduces the subject assignment and some essential background, after which the students engage in the assignment. The assignment descriptions and, if applicable, accompanying files are available via electronic support during the course. The lecturer and assistant will be available for supervision and help. During the assignment, the lecturer will also plenary discuss related theoretical issues and examples. When the assignment is not finalized within the 6 hrs of the class, the students are expected to finalize on an individual account.

8. Facilities

The course will take place in the facilities of Faculdade de Motricidade Humana, Universidade de Lisboa.

Each student must bring her/his own personal computer with MatLab (with Simulink Toolbox) installed. There a student version or a free trial version which can be downloaded from <https://www.mathworks.com/campaigns/products/trials.html>
https://www.mathworks.com/academia/student_version.html

9. Calculation study load (note that this is an exemplary calculation)

Classes:	5*6	=	30 hrs
Preparation lectures and practicals	5*2	=	10 hrs at least!
Total		=	40 hrs

10. Programme per day

Day 1

Literature to prepare before this class (in the following order):

- De Poel, H.J. (2019). *Introductory text for 'Introduction to Dynamical Systems'*
- Fuchs (2013): Chapter 1 & Appendix B (p205-206);
- Assignment 1, description & background

The first class will provide a brief overview of the course; introduction to the main subjects of study; (re-)introduction and discussion of concepts like dynamics, dynamical systems, differential equations. Assignment 1: We will collectively take the first guided steps in Simulink, and work on assignment 1. This involves numerical simulation of a linear 1st order system, and subsequently take first steps in the numerical analysis of a linear 2nd order system.

Day 2

Literature to prepare (in the following order):

- Fuchs (2013): §10.1 ,10.2 & 10.3; §3.1 & 3.2;
- Assignment 2, description & background.

Class 2: Key concepts will be introduced and discussed: *fixed points* and *stability*. To be able understand these concepts exactly, this lecture needs to discuss some mathematical bases like complex numbers, eigenvalues and –vectors, and discuss the importance of these issues alongside the analysis of a linear 2nd order system.

Assignment 2 will continue on linear(ized) 2nd order systems. We will make simulations of the linear hanging pendulum, harmonic mass-spring, and linear inverted pendulum, and analyze their behaviors alongside several dynamical tools (e.g. phase plots).

Day 3

Literature to prepare:

- Fuchs (2013): Chapter 2 until §2.2 (p21); §3.4, §3.8
- Khoo (2018): Chapter 1
- Pikovsky et al. (2001): Chapter 2
- Assignment 3, description & background

In this very important lecture, we turn from linear(ized) systems to non-linear systems, classify types of fixed point attractors, and introduce the so-called limit cycle attractor. Differences between the linear vs non-linear variants will be explored alongside concepts such as resonance, phase locking, and entrainment.

Assignment 3 involves simulation of a nonlinear mass-spring oscillator (vd Pol) and the general (i.e., nonlinear) pendulum model, and explores distinctive effects of forcing and feedback.

Day 4

Literature to prepare:

- **Assignment 4, description & background**

- **Fuchs (2013): §1.3, §2.2 - 2.4, §3.6 -3.7;**

Here we further discuss feedback in terms of coupling between components/nodes. Next, we take a step back and reiterate on the previous weeks, before continuing on nonlinear dynamics in general, and more specifically in relation to potential functions and Lyapunov functions.

Assignment 4: Simulating and analyzing a system of coupled linear oscillators vs. a system of two coupled vd Pol oscillators. Next, we will simulate and analyze potential functions / Lyapunov functions and relate the according outcomes to results of previous assignments.

Day 5

Literature to prepare:

- **Fuchs (2013): §6.1, 6.2, 6.7; Chapter 4;**

- **Assignment 5, description & background**

The final day involves discussion of concepts in the context of variability, noise and determinism: colored (e.g. pink) noise, chaos, fractality, stochastic resonance.

Assignment 5: By means of numerical simulations, we will have a closer look into the concept of noise by simulating different 'colors' of noise, and examine quantitatively how noise affects system's dynamics. We will add noise in Simulink models that were constructed in previous assignments. Furthermore, we will simulate a simple, completely deterministic system that shows chaotic dynamics: the Lorenz system. Outcomes of these assignments will be examined in terms of variability, stability, etc, by adopting some oft-used data-analysis methods developed in the area of dynamical systems.
