Nonlinear Systems

1. **Course number and name:** 020SNLES5 – Nonlinear Systems

2. **Credits and contact hours:** 4 credits, 2x1.15h contact hours per week

3. **Instructor's or course coordinator's name:** Hadi Kanaan

4. **Instructional materials:**

   a. **Textbooks:** R. R. Mohler, *Nonlinear Systems. Volume 1, Dynamics and Control*, Prentice-Hall, 1991; Jean-Jacques E. Slotine and Weiping Li, *Applied Nonlinear Control*, Prentice-Hall, 1991

   b. **Other supplemental materials:** Notes, exercises, PowerPoint presentations

5. **Specific course information**

   a. **Catalog description:**
   This course is divided into two parts. The first part presents two analysis methods of nonlinear systems. The first method, characterized by its simplicity, is based on the describing function concept in the frequency domain. It makes use of basic elements already seen in linear systems analysis and control, which are extended to the nonlinear case. The second method is more rigorous and uses the concept of state variables and phase plane in the time domain. The stability theory of nonlinear systems study will be presented in both frequency and time domains (Loeb criterion, Lyapunov theorem). In the second part of the course, two nonlinear time-domain control techniques are presented: the sliding-mode control known by its robustness, and the feedback linearization control characterized by its precision. The advantages and drawbacks of these two control methods with respect to conventional techniques will be underlined. Their application in the control design of nonlinear industrial processes will also be illustrated.

   b. **Prerequisites:** None

   c. **Selected Elective** for EE students.

6. **Educational objectives for the course**

   a. **Specific outcomes of instruction:**
   The students will be able to:
   - Calculate the describing function of any symmetric nonlinear function.
   - Analyze the oscillatory behavior of a feedback nonlinear system in the frequency domain.

- Develop the state model and compute the trajectories of a nonlinear dynamic system in the phase plane.
- Determine the local and global stability of equilibrium points using Lyapunov method.
- Design, develop and implement a sliding-mode control law for a dynamic system.
- Design, develop and implement an input-state or input-output feedback linearization control law for a dynamic system.
- Simulate and analyze the behavior and performance of a nonlinear feedback control system.

b. PI addressed by the course:

KPI	1.1	1.2	1.3	3.1	3.2	6.3	6.4	7.1
Covered	x	x	x					
Assessed		x	x	x	x	x	x	x
Give Feedback		x	x		x	x	x	x

7. Brief list of topics to be covered:

- ✓ Introduction to nonlinear systems and functions. Type of nonlinearities. Analysis methods. Class of nonlinearity separated systems. Hammerstein and Wiener modeling methods of nonlinear systems (1.25 hours)
- ✓ Describing function method: principle and applications (2.5 hours)
- ✓ Analysis of auto-oscillatory systems and stability study using Loeb criterion (1.25 hours)
- ✓ Frequency response and synchronization. Step response (1.25 hours)
- ✓ Series connection of nonlinear blocks (1.25 hours)
- ✓ Harmonic oscillators. Tunnel diode. Tuning (2.5 hours)
- ✓ Phase plan method (2.5 hours)
- ✓ Lyapunov stability analysis (2.5 hours)
- ✓ Dead-beat relay control of a servomotor (2.5 hours)
- ✓ Sliding mode control. Sliding surface. Filippov theorem. Chattering problem (5 hours)
- ✓ Feedback linearization control. Lie derivative. Lie bracket. Frobenius theorem (2.5 hours)
- ✓ Input-state feedback linearization control of multivariable systems (1.25 hours)
- ✓ Input-output feedback linearization control of single-input-single-output systems. Inner dynamics. Extension to multi-input-multi-output systems (1.25 hours)
- ✓ Exercises (2.5 hours)