1CC3000 – Model representations and analysis

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Department: DÉPARTEMENT AUTOMATIQUE
Language of instruction: ANGLAIS, FRANCAIS
Campus: CAMPUS DE PARIS - SACLAY
Workload (HEE): 60
On-site hours (HPE): 36,00

Description

Current technological and scientific progress would not have arisen without the deep understanding and evolution of complex systems gathering different application fields such as energy, telecommunications, transport, aeronautics and aerospace, economy, finance, healthcare, etc. System modeling plays a crucial role to drive it and to analyse interactions between its components or with other systems.

The students will be expected to be able to represent the behavior of a system with a model that can be exploited either analytically or digitally, well-suited to the model goal in link with some modeling assumptions both in terms of representativeness and complexity, and to evaluate its domain of validity.

To that aim, they will be able to choose the relevant spatial and time scales and to select the most appropriate representation (discrete or continuous). Based on experimental data, they will be expected to be able to define the model structure, to identify its parameters despite inherent measurement noises, and to assess the relevance/validity of the model.

Quarter number

ST2

Prerequisites (in terms of CS courses)

Analysis, Probabilities, Basics of Computer Sciences.

Syllabus

1) General introduction : from a system to a formal mathematical expression [Lecture 1h30]

• Model taxonomy (discrete / continuous / hybrid, deterministic / stochastic, mechanistic /data-driven, ...)

• Modeling approach and methodology

2) Modeling of continuous-state systems [Lectures 6h00 ; Tutorials: 4h30]
• Time representation of dynamical systems:
o Continuous time systems: state-space representation of a differential equation (linear or nonlinear), linearization around an equilibrium point, linear state-space model and its explicit solution, stability analysis by mean of an eigenvalue study.
o Discrete time systems: state-space representation of a difference equation (linear or nonlinear), linearization around an equilibrium point, linear state-space model and its explicit solution, stability analysis by mean of an eigenvalue study.
• Frequency representation:
o Transfer function of a continuous time linear and time invariant system: basic concepts on Laplace transforms, frequency response (Bode diagram), time response (impulse response, step response, focus on 1st and 2nd order systems), link with the state-space representation
o Transfer functions of a discrete time linear and time invariant system: basic concepts on z transform, link with state-space representation

3) Modeling of discrete-state systems [Lectures : 3h00; Tutorials: 3h]
• Automata
o Untimed automata, synchronous and parallel products of automata
o Timed automata, clock structure, guard and invariance conditions
• Petri nets
o Formalization of untimed Petri nets, process modeling (resource sharing, synchronization...), linear algebra analysis, properties of a Petri net
o Extension to the case of timed Petri nets
• Hybrid systems
o Formalization, guard and invariance conditions, continuous state reset function

4) Methods for the sensitivity analysis, the parameter identification and the evaluation of models [Lectures : 4h30 ; Tutorials: 4h30]
• Uncertainty and sensitivity analysis
o Modeling of uncertainties: modeling from available data (histograms, kernel methods, estimation of the mean and variance), principle of maximum entropy
o Propagation of uncertainties: interval computation, combination of variance, Monte Carlo approach
o Sensitivity analysis: case of linear or quasi-linear systems, Sobol indices
• Model assessment
o Identifiability, basics of parameter identification (least square method, based on frequency response, based on time response), digital optimization, AIC (Akaike Information Criterion) / MSPE (Mean Squared Error of Prediction)
• Applications of the parameter estimation method for a simple model, linear/non-linear regression

5) Illustration and application of the modeling approach [Lecture : 1h30; Tutorials: 3h00]
• Epistemology of models and simulations (Franck Varenne, lecture : 1h30).
• Tutorial on the modeling approach on real-life problems

6) Written final exam [3h]

7) In parallel, students will have to carry out a project as part of their workload (and not during contact hours). A time slot is provided for Q&A with the teaching team. [Project : 1h30 in person]

Class components (lecture, labs, etc.)
See syllabus

Grading
Mandatory assessments:
- Written final exam (3h): 75% of the module mark - individual, all documents and calculator allowed;
- Project : 25% of the module mark, by groups of 3 students;
- During this course, the C1 skill will be assessed through the final exam and the project.

Course support, bibliography

- T. Chevet, S. Font, M.A. Lefebvre, V. Letort-Le Chevalier, H. Lhachemi, C. Maniu, G. Sandou, C. Vlad (2021) "Modélisation. Représentations et analyse des modèles", Polycopié CentraleSupélec, 3nd edition in French, Gif-sur-Yvette.
- T. Chevet, S. Font, M.A. Lefebvre, V. Letort-Le Chevalier, H. Lhachemi, D. Madhavan Brochier, C. Maniu, G. Sandou, C. Vlad (2021). "Model Representations and Analysis", Polycopié CentraleSupélec, 2nd edition in English, Gif-sur-Yvette.
- Walter, É., & Pronzato, L. (1994). Identification de modèles paramétriques à partir de données expérimentales. Masson.
- Lamnabhi-Lagarrigue, F, Annaswamy, A, Engell, S, Isaksson, A, Khargonekar, P, Murray, RM Nijmeijer, H, Samad, T, Tilbury, D & Van den Hof, P 2017, 'Systems & Control for the future of humanity, research agenda : Current and future roles, impact and grand challenges' Annual Reviews in Control, vol 43, pp. 1-64.
- Saltelli, A. et al. (2008). Global sensitivity analysis: the primer. John Wiley & Sons.

Resources

- Teaching staff (instructor(s) names):
  Stéphane FONT, Véronique LETORT-LE CHEVALIER, Hugo LHACHEMI, Cristina MANIU, Guillaume SANDOU, Cristina VLAD
- Target size for tutorial groups : 2x12 groups of 40 students
  List to be confirmed:
  Stéphane FONT, Véronique LETORT-LE CHEVALIER, Hugo LHACHEMI, Cristina MANIU, Guillaume SANDOU, Cristina VLAD, Pedro RODRIGUEZ, Chengfang REN, Israel HINOSTROZA, Jacques ANTOINE, Richard COMBE, Joy EL FEGHALI, Jean AURIOL
- Software, number of licenses required : Matlab
- Equipment for tutorials classrooms: Tutorials in standard rooms (blackboard, videoprojector, Wifi), with student laptops.

Learning outcomes covered on the course
At the end of this course, students will be able to :
1. Choose the right model typology, that is well-suited to the model objective (simulation, optimization, control…): discrete/continuous, mechanistic (based on physical laws) /data driven (based on measured data), frequency/time based.
2. Model and analyze a continuous process, by using time and / or frequency representations; use basic parameter identification techniques based on a time or frequency response (e.g. least squares methods from frequency or time measurements).
3. Model and analyze a discrete process in a relevant framework including automata, Petri nets, and discrete-events simulation.
4. Take a critical approach and analyze the reliability of the developed models: uncertainty propagation, sensitivity analysis (local and global methods based in particular on variance), selection of a model with regards to certain specifications.
5. Digitally implement the obtained model, simulate and validate, particularly in comparison with experimental data.

Description of the skills acquired at the end of the course
In terms of skills:
- The first three items "**Acquis d'apprentissage"** contribute to core skills C1.1 "Analyze: study a system as a whole, the situation as a whole. Identify, formulate and analyze a system within the framework of a transdisciplinary approach with its scientific, economic, human dimensions, etc." and C1.2: "Modeling: using and developing the appropriate models, choosing the right modeling scale and the relevant simplifying assumptions".
- Items 4 et 5 correspond to core skill C1.3: "Solve: solve a problem with a practice of approximation, simulation and experimentation".

- Item 5 addresses core skill C1.4: "Design: specify, implement and validate all or part of a complex system".
- Tutorials and projects will give the opportunity to deepen core skill C8.1: "Build the collective to work as a team", as well as core skill C6.1: "Solve a problem numerically".
- The project with a peer-to-peer evaluation scheme will contribute to core skill C7.2: "Know how to convince: On the relationship with others: Understand in an evolutionary way the needs and expectations of his interlocutors. Encourage interactions, be a teacher and create a climate of trust".