ELLIIT Ph.D. Course:
Advanced Motion Planning and Control

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January 12, 2021

Today's Meeting

- About the course.
- Introduction of participants.
- Course administration.
- Planning of next meeting.

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About the Course (1/2)

- Focus on advanced motion planning and control in a general context (robotics, autonomous cars, UAVs, etc.).
- Focus on understanding and practical use of different methods in these areas.
- Course history: Given at LiU in 2016 and at LU in 2017.
  - Foundation for TSFS12: Autonomous Vehicles—Planning, Control, and Learning Systems at LiU from 2019.
- Course relates to several ongoing research projects in the ELLIIT and WASP research programs.

About the Course (2/2)

- Many methods developed within the robotics community during the last decades.
  - Also applicable for wheeled vehicles and other mechanical systems after generalizations.
- Course will cover both motion *planning* and *control*.
- Course homepage:
  `https://www.fs.isy.liu.se/Edu/Courses/MotionPlanning/`
- Responsible for the course:
  - Björn Olofsson (`bjorn.olofsson@liu.se`)
  - Erik Frisk (`erik.frisk@liu.se`).

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Björn Olofsson (1/2)

- M.Sc. in Engineering Physics from Lund Univ. June 2010, Master's Thesis in the Robotics Lab on decoupled motion planning and path-following control.
- Ph.D. from Dept. Automatic Control, Lund Univ. September 2015.
  - Thesis: *Machining with industrial robot manipulators and optimal motion control of vehicles and robots*.
- Now affiliated with both LiU/Vehicular Systems and LU/Automatic Control.

Björn Olofsson (2/2)

- Part of the ELLIIT program since 2012, involved in several projects with collaboration between LiU and LU.
- Involved in two European robotics-research projects as a Ph.D. student, COMET and SMErobotics.
- Involved in WASP research as co-supervisor since 2016.
- Research interests in motion planning, autonomous vehicle and robot motion control, and related research in system identification and state estimation.

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Organization of the Course (1/2)

- Approximately one meeting per week, held in Zoom.
- Meetings nominally held on Tuesdays at 15.15–17.00 (exceptions may occur).
- Combination of lectures by the participants, guest lecturers, Erik Frisk, and Björn Olofsson.
- Project seminar tentatively to be held on May 21, 2021, at 13:15-15:00.
- Weekly reading assignments and (implementation) exercises during selected weeks.

Organization of the Course (2/2)

- For each meeting, one participant is assigned in advance to be responsible.
- The responsible person prepares a lecture (approx. 45 minutes) on the studied material.
- Joint discussion after the lecture on the algorithms and results of the exercises, led by the responsible person, Erik, and Björn.
- Varying background and previous courses taken among participants.
  - Assignments in the course will be adapted depending on if taken TSFS12 or not.
  - The important aspect is to learn new content in the course.

Weekly Assignments (1/2)

- Focus on implementation and practical evaluations of the methods on small examples in the exercises for learning and investigations of the studied material.
- Several interesting exercises available in the course literature (and on the internet).
- Assignments defined during the meeting for the following week.
  - Code base (Python and Matlab) from TSFS12 will be used in some of the assignments.
  - Possible to use software libraries from the internet (of course with reference).

Weekly Assignments (2/2)

- Material from the course TSFS12 available at `https://gitlab.liu.se/vehsys/tsfs12`.
  - Lecture videos only accessible within LiU.
  - Other participants can get access on request to Björn.
- Submit assignments to `bjorn.olofsson@liu.se` *before each meeting*.
- No extensive written reports required, files with commented code and accompanying plots (with conclusions from the results) are sufficient.
- Please be prepared to present your results in class/Zoom during the meeting.

Literature

- The planning part is based on the book:
  LaValle, S. M., *Planning Algorithms*, Cambridge University Press, Cambridge, UK, 2006.
  - Available for free download at the homepage of the author:
    `http://lavalle.pl/planning/`.
- Selected chapters from B. Siciliano & O. Khatib (Eds.), *Springer Handbook of Robotics* will also be used as literature.
- The control part will be based on selected book chapters.
- The books will be complemented by several articles and papers (announced during each meeting for the following week).

Guest Lectures

- Guest lectures will be given by invited speakers during the course.
- Will give focused lectures on specific topics related to their own research.
- Speakers and exact times will be announced well in advance (might be outside of nominal schedule though).

Projects

- The final part of the course will be devoted to individually performed projects.
- Extended theoretical and simulation-based study of selected algorithm(s) or implementation of a method on a suitable hardware platform.
- Experiments can, e.g., be performed using the Robot Operating System (ROS), the PythonRobotics Toolbox, or the Open Motion Planning Library (OMPL).
- Preferably related to own research (possible conference paper).

Suggestions for Projects (1/3)

- Implement a complete motion-planning algorithm from the course on an appropriate hardware platform (e.g., ground vehicle or aerial vehicle), either with stationary or time-varying obstacles.
- Explore how motion planning and control could be combined with learning (for example, trade-off between exploration and utilization of already acquired information in reinforcement learning). Study articles and do evaluations in simulation or experiments.

Suggestions for Projects (2/3)

- Study motion planning under uncertainty and sensor-based inputs (see Part III in the book by LaValle). Evaluate a few algorithms in simulation.
- Explore methods for structured and efficient decomposition of, and subsequent search, in the free configuration space (see Chapter 6 in the book by LaValle on combinatorial methods).

Suggestions for Projects (3/3)

- Select a certain class of motion-planning algorithms and study the latest articles within the field to define state-of-the-art. Implement and evaluate some of the algorithms in simulation or experiments.
- Your own project ideas.
- Project idea from your own research.

Examination

In order to receive course credits, the participant is required to:

- Attend the weekly meetings and actively take part in the discussions.
- Submit the hand-in assignments prior to each meeting where it is requested (primarily implementation code or scripts with comments and conclusions from the results, no extensive written reports required).
- Prepare one lecture during the course.
- Complete a final project, give an oral presentation at the project seminar, and submit a written report.
- Course nominally 6+3 hp (where the first part primarily comprises the planning part).

Examiner for the course is Björn Olofsson.

Tentative Week Plan (1/2)

- **Week 3:** Introduction to motion planning and control & discrete graph search (Responsible: Björn)
- **Week 4:** Motion planning fundamentals
- **Week 5:** Rapidly-exploring random trees (RRTs) and extensions
- **Week 6:** Motion primitives and lattice planning
- **Week 7:** Feedback-based planning and artificial potential fields
- **Week 9:** Invariant-set motion planning (Responsible: guest lecturer)

Tentative Week Plan (2/2)

- **Week 10:** Trajectory optimization for planning and control
- **Week 14:** Path and trajectory-following control
- **Week 15:** Model predictive control for planning and control
- **Week 16:** Motion prediction for planning and control
- **Week 17:** Planning and control architectures
  (Responsible: Björn, Erik, and guest lecturer)
- **Week 21:** Project seminar
  (Responsible: Björn)

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Assignments for Meeting on Jan. 19, 2021 (1/2)

- Send your preferences for lecture responsibility before the weekend to Björn.
  - Schedule will be sent via mail and presented during meeting next week.
- Read Chapters 1–2 in LaValle, S. M., *Planning Algorithms*, Cambridge University Press, Cambridge, UK, 2006.
- Read the survey paper B. Paden et al., "A survey of motion planning and control techniques for self-driving urban vehicles". IEEE Transactions on Intelligent Vehicles 1.1, 33–55, 2016.

Assignments for Meeting on Jan. 19, 2021 (2/2)

- Read the paper M. Likhachev et al., "ARA*: Anytime A* with provable bounds on sub-optimality", Advances in Neural Information Processing Systems, 16, 767–774, 2003.
- Do Hand-in Exercise 1 from TSFS12 (discrete graph search). Those that have taken TSFS12 extend towards real-time graph search with replanning, such as ARA*.
- **Next meeting: Tuesday January 19, 2021, at 15:15 in Zoom**.