Aalto University
School of Electrical
Engineering

ELEC-E8740 — Course Overview and Introduction to Sensor Fusion

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Contents

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Zulip support, grading

Intended Learning Outcomes of The Course

After successfully completing this course, you are able to:

- explain the principles and components of sensor fusion systems,
- identify and explain the differences between linear and nonlinear models and their implications on sensor fusion,
- construct models of multi-sensor systems and use least-squares algorithms for sensor fusion,
- construct continuous and discrete time state-space models based on ordinary differential equations, difference equations, and physical sensor models,
- develop and compare state-space models and Kalman as well as particle filtering algorithms for solving sensor fusion problems.

Schedule

- 10+2 lectures
  - Tuesday, 12:15 - 14:00 in TU2.
  - Detailed schedule (incl. topics) on MyCourses
  - Previous year's recorded (Zoom) lectures will be available as backup
- 10+2 exercise sessions
  - Exercise sessions are on Fridays, 12:15 - 14:00 in AS2.
  - Exercises start on Friday, September 9, 2022.
- First exam is on Monday, October 17, 2022 at 9-12.
- Second exam is on Friday, December 9, 2022 at 13-16.
- The tentative project work deadlines are Sunday, November 20, 2022, and Sunday, December 18, 2022.

Check MyCourses regularly for updates!

Course Material and Zulip

- Lecture notes and slides are the main course literature
  - Lecture notes ($\sim$ course book) are already available on the course homepage in MyCourses.
  - Slides will be made available in MyCourses just before each lecture.
- There is also Zulip chat space for the course (see MyCourses).

Exercises and Homeworks

- Exercise sessions are held on Fridays, 12:15 - 14:00 in AS2, starting on Friday, September 9, 2022.
- In the exercise sessions, the teacher shows you hands on how to solve the exercises.
- Pen & paper and computer exercises (mainly Python)
- Exercise sessions are not mandatory but highly recommended – the exam questions are likely to be related to the exercises
- In the end of each exercise paper there is a homework. Homeworks affect grading.
    - The homeworks need to be generally returned on MyCourses before the next exercise session day at 12:00.

Assessment and Grading

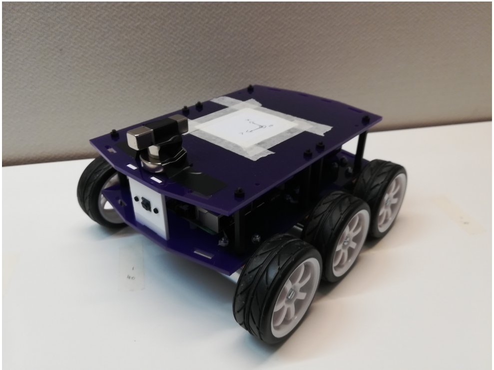
- The high level formula for the grade is

$$\text{final grade} = \max\left(\text{exams+homework grade}, \text{project grade}\right)$$

- You still must pass both the exams+homework and project!
- The exams and homeworks give total of 100 points, which determine the grade via mapping $\geq 50 pts \leftrightarrow grade\ 1$, $\geq 60 pts \leftrightarrow grade\ 2$, $\geq 70 pts \leftrightarrow grade\ 3$, $\geq 80 pts \leftrightarrow grade\ 4$, $\geq 90 pts \leftrightarrow grade\ 5$.
- Each of the 2 exams give maximum of 30 points and the homeworks (10) give 4 points each.
- The project work grading is clarified later.

Project work

- Track an autonomous robot using multiple sensors
- Details of the project work will be provided later.



Presemo Questionnaire

- We are using presemo on this course.
- Please use your computer or mobile phone and go to:

`http://presemo.aalto.fi/fusion`

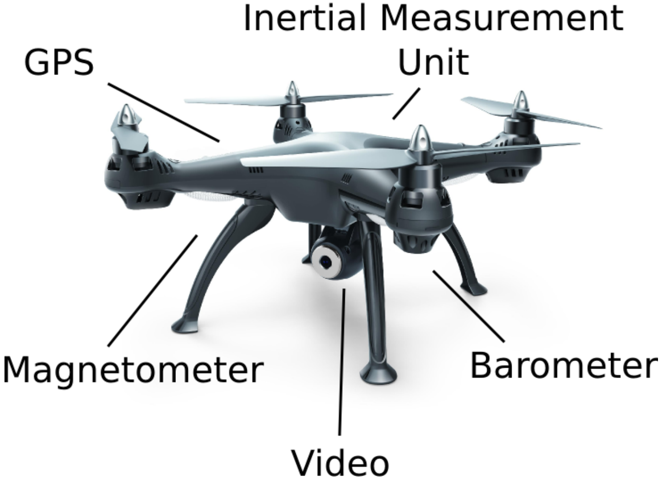
Definition of Sensor Fusion

- One possible definition of sensor fusion:

  "computational methodology which aims at combining the measurements from multiple sensors such that they jointly give more information on the measured system than any of the sensors alone."

- The important aspects are:
  - It is computational methodology.
  - Uses measurements from multiple sensors.
  - Attempts to use the information from all the sensors jointly.

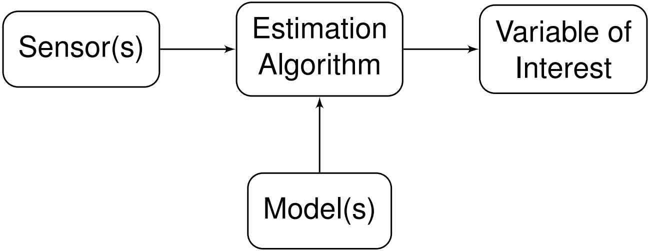
Sensor Fusion Applications: Drones



Sensor Fusion Applications: Autonomous Cars

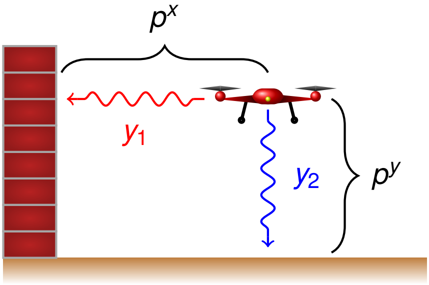
Sensor Fusion Applications: Smartphones

The Components of Sensor Fusion



Model of a Drone (1)

- We measure y_1 with e.g. radar or ultrasound.
- We measure y_2 with e.g. radar or barometer.
- We wish to "fuse" the sensor measurements to get the location (p^x, p^y).
- The model in this case is



$$y_1 = p^x + r_1,$$
$$y_2 = p^y + r_2.$$

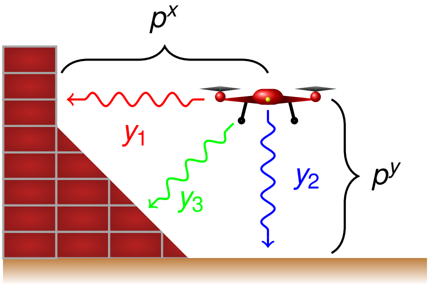
(r_1 and r_2 here denote measurement noises)

- Sensor fusion amounts to just $p^x \approx y_1$ and $p^y \approx y_2$.

Model of a Drone (2)

- We could also measure the distance y_3 to an additional tilted wall.
- The model now becomes

$$y_1 = p^x + r_1,$$
$$y_2 = p^y + r_2,$$
$$y_3 = \frac{1}{\sqrt{2}}(p^x - x_0) + \frac{1}{\sqrt{2}} p^y + r_3.$$



- In vector form:

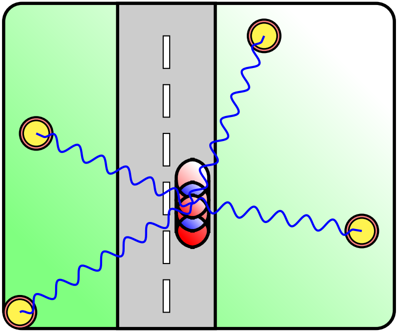
$$\mathbf{y} = \mathbf{G}\,\mathbf{x} + \mathbf{b} + \mathbf{r}.$$

- Linear least squares method gives $\mathbf{x} = (p^x, p^y)$.

Model of an Autonomous Car (1)

- We measure relative positions of M landmarks.
- We get $2M$ measurements ($M = 4$ here):

$$
\begin{aligned}
y_1 &= s_1^x - p^x + r_1, \\
y_2 &= s_1^y - p^y + r_2, \\
&\vdots \\
y_{2M-1} &= s_M^x - p^x + r_{2M-1}, \\
y_{2M} &= s_M^y - p^y + r_{2M}.
\end{aligned}
$$



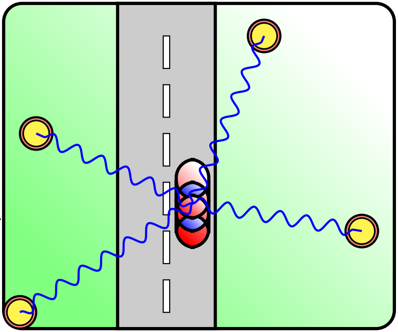
- Again leads to form

$$\mathbf{y} = \mathbf{G}\,\mathbf{x} + \mathbf{b} + \mathbf{r}.$$

Model of an Autonomous Car (2)

- We only measure the range to each landmark.
- In that case we have

$$y_1^R = \sqrt{(s_1^x - p^x)^2 + (s_1^y - p^y)^2} + r_1^R,$$
$$\vdots$$
$$y_M^R = \sqrt{(s_M^x - p^x)^2 + (s_M^y - p^y)^2} + r_M^R.$$



- This is a non-linear model

$$\mathbf{y} = \mathbf{g}(\mathbf{x}) + \mathbf{r}$$

- Non-linear least squares method is needed.

Dynamic Models

- The object of interest might also be moving.
- We can model time-continuity with a dynamic model.
- For example, we might have

$$\mathbf{x}_n = \mathbf{x}_{n-1} + \mathbf{q}_n \qquad \text{(here } \mathbf{q}_n \text{ is a noise process)}$$

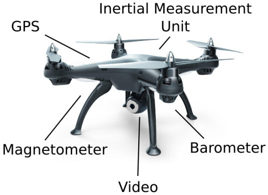
- More generally we get state-space models of the form

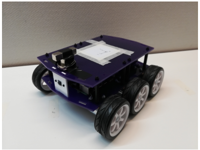
$$\begin{aligned} \mathbf{x}_n &= \mathbf{f}(\mathbf{x}_{n-1}) + \mathbf{q}_n, \\ \mathbf{y}_n &= \mathbf{g}(\mathbf{x}_n) + \mathbf{r}_n. \end{aligned}$$

- Can be coped with Kalman filters, and extended/unscented Kalman filters.

Technical Contents of the Course

- Formulation of sensor fusion as a least squares problem.
- Solution methods for linear least squares problems.
- Solution methods for non-linear least squares problems.
- Solution methods for dynamic least squares (state-estimation) problems.
- Implementation of the methodology to robot platform.



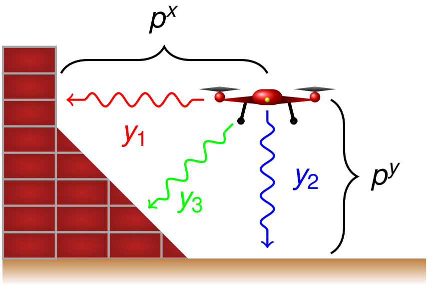


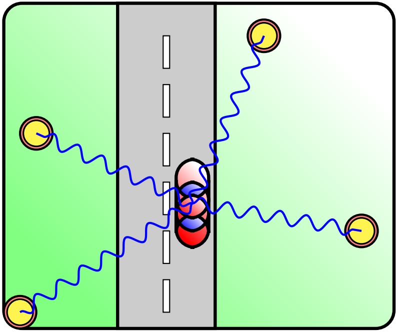
Summary (1)

- Lectures are on Tuesdays in 12:15-14:00
- Exercises on Fridays in 12:15-14:00
- Teaching materials are lecture notes and slides on MyCourses.
- Project work starts later and it is about sensor fusion in a mobile robot.
- There are two mid-term Exams.
- The grade is determined by exams, homeworks, and project work.
- Sensor fusion is methodology for intelligent processing of measurements from multiple sensors.
- In practice, linear/non-linear least squares methods and Kalman filtering methods.

Summary (2)

Typical models that we saw are the following:





$$\mathbf{y} = \mathbf{G}\,\mathbf{x} + \mathbf{b} + \mathbf{r}$$

$$\mathbf{y} = \mathbf{g}(\mathbf{x}) + \mathbf{r}$$

Presemo Questionnaire

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