Aalto University
School of Electrical
Engineering

# ELEC-E8740 — Course Overview and Introduction to Sensor Fusion

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**Aalto University**

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# Contents

# The Team

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# 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 (1)

- 12 virtual lectures
  - Fridays, 12:15 - 14:00 in Zoom, the lectures are recorded.
  - Individual link for each lecture (to ease recording).
  - Detailed *preliminary* schedule (incl. topics) on MyCourses
- 11 virtual exercise sessions
  - Exercise sessions are on Tuesdays, 12:15 - 12.00 in Zoom.
  - Exercises start on Tuesday, September 15, 2020.
- No lectures or exercise sessions on the exam week 19.10. - 23.10.
- Exam on Friday December 11, 2020, 12.00 - 15.00 on MyCourses.

Check MyCourses regularly for updates!

# Course Literature

- 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.
- Recorded Zoom-lectures will be available on MyCourses (unless the recording fails as it sometimes does).
- Optional textbook:
  - Gustafsson, F. (2018). Statistical Sensor Fusion. Studentlitteratur, 3rd edition.
  - Very complete (and more extensive) treatment of the subject
  - Not required to pass the course
  - Good reference for the future

# Assessment and Grading

## Assessment

To pass this course, you need to:

- pass the *written exam*,
- pass the *project*.
- get at least 3 points from *homeworks*.

## Online Exam

- Online exam in MyCourses,
- Allowed aids: anything, but you cannot communicate with others, plagiarism will be checked.

## Grading

- The grading scale is *0–5*,
- The final grade is the maximum of the exam and project.

# Exercise Sessions

- Exercise sessions are held on Tuesdays, 12:15 - 14.00 in Zoom, starting on Tuesday, Sep 15, 2020.
- In the exercise sessions, the teacher shows you hands on how to solve the exercises.
- You also have the chance to solve the exercises yourself.
- Pen & paper and computer exercises
    - Matlab or Octave recommended, Python is possible
- Exercise sessions are not mandatory but highly recommended, the exam questions are likely to be related to the exercises

# Homeworks

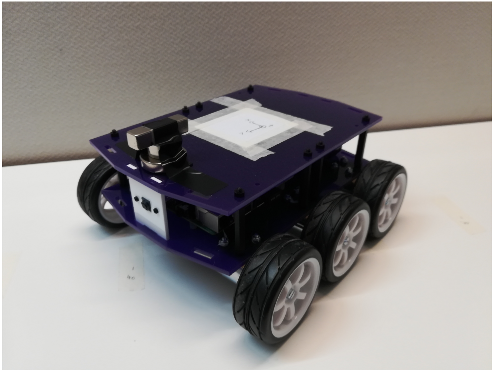
- In the end of each exercise paper there is a homework.
  - You must complete at least 3 homeworks (out of 11) to pass the course.
  - From each homework exceeding 3 you can get 1/2 point to exam:

$$\text{extra exam points} = \max(0, (n-3)/2),$$

  where $n$ is the number of returned homeworks.
- The homeworks need to be returned on MyCourses before the next exercise session day at 12:00.

# 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`

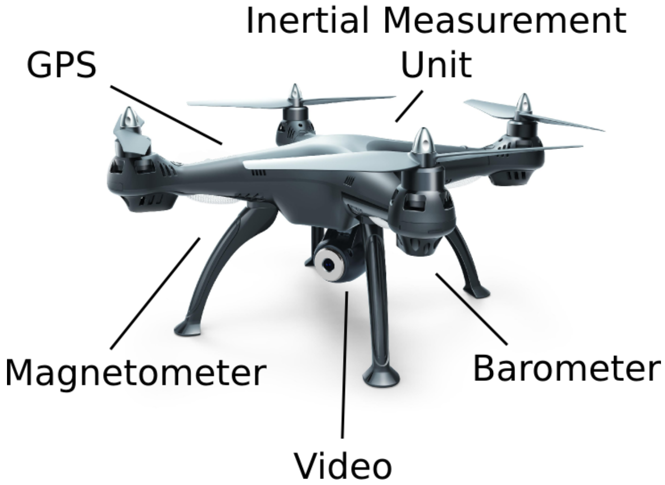
# Definition of Sensor Fusion

- 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.

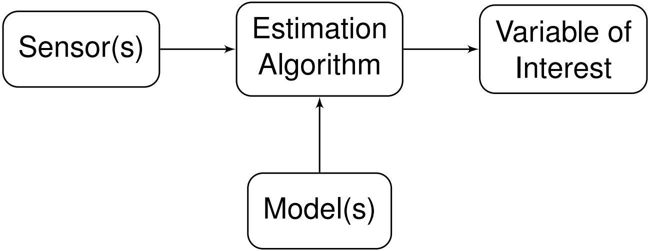
# Sensor Fusion Applications: Drones



# Sensor Fusion Applications: Autonomous Cars

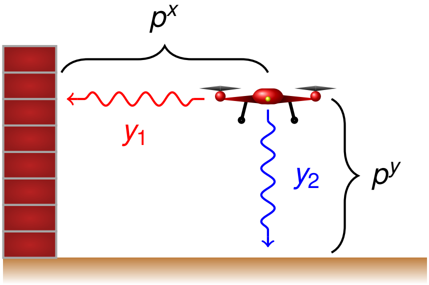
# Sensor Fusion Applications: Smartphones

# 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)

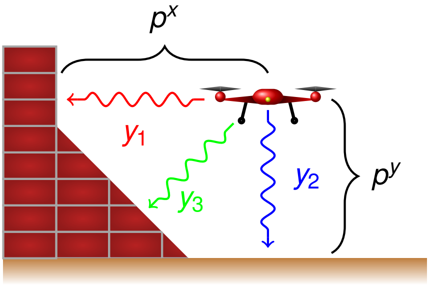
- We could also measure the distance $y_3$ to an additional tilted wall.
- The model now becomes

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

- In vector form:

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

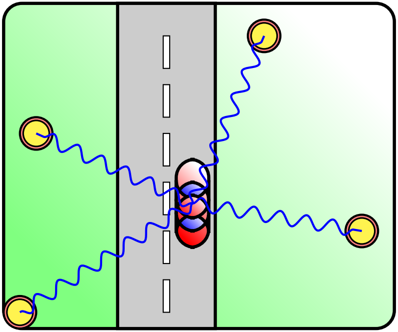
- Linear least squares method gives $\mathbf{x} = (p^x, p^y)$.



# Model of an Autonomous Car (1)

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

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



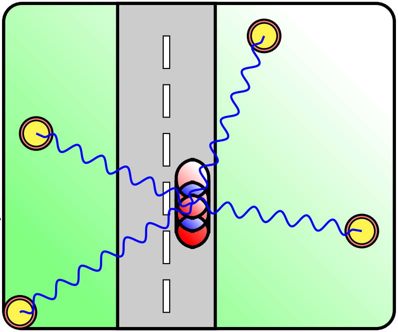
- Again leads to form

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

# 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

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

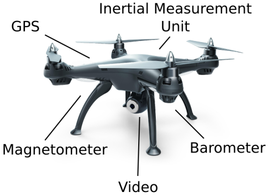
- More generally we get state-space models of the form

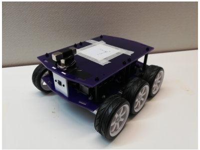
$$\begin{aligned} \mathbf{x}_n &= \mathbf{f}(\mathbf{x}_{n-1}) + \mathbf{q}_n, \\ \mathbf{y}_n &= \mathbf{g}(\mathbf{x}_n) + \mathbf{r}_n. \end{aligned}$$

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



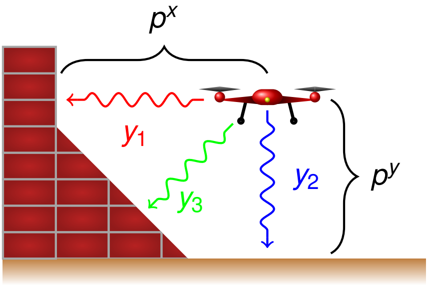



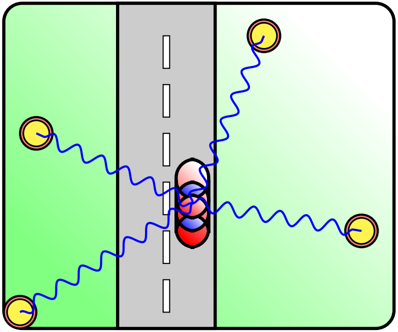
# Summary (1)

- Zoom lectures are on Fridays in 12:15-14:00
- Zoom exercises on Tuesdays 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.
- Exam is in early December and project work deadline just before Christmas.
- Homeworks earn points to exam.
- Sensor fusion is methodology for intelligent processing of measurements from multiple sensors.
- In practice, linear/non-linear least squares methods and Kalman/particle 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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