Sensors and Sensing
Introduction

Todor Stoyanov

Centre for Applied Autonomous Sensor Systems
Örebro University
Sweden

Outline

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Welcome to Sensors & Sensing!

Course instructor
Todor Stoyanov
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Office hours: Wednesdays,
15:00 - 17:00

Lab instructor
Püren Güler
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What will you learn in this course?

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In this course you will learn about:

- standard sensors used on mobile robotic platforms
- principles of operation of different types of sensors
- configuration, calibration and use of sensors for mobile robots
- limitations and advantages of different sensors in different application contexts
- algorithms for processing raw sensor information

What will you learn in this course?

You will also acquire some “soft”skills:

- Working in a team, solving real-world problems.
- Writing about your work in appropriate scientific writing.
- How to not be afraid to “get your hands dirty”.

Outline

Course Outline

Session	Contents
L1, 05. Sep	Introduction to Sensors and Sensor Systems
L2, 06. Sep	Microcontrollers, Signals, and I/O
L3, 11. Sep	Motors, Encoders and Control
L4, 13. Sep	Robot Kinematics
L5, 18. Sep	Range Sensing
P1, 19. Sep	Lab 1: Arduino and I/O
L6, 20. Sep	Cameras
L7, 25. Sep	3D Range Sensing
P2, 26. Sep	Lab 2: ROS Arduino & differential drive
L8, 26. Sep	Filtering

Course Outline

Session	Contents
L9, 09. Oct	Pose Sensors and Localization Systems
P3, 10. Oct	Lab 3: Range Sensing
L11, 11. Oct	Point Cloud Processing
L11, 16. Oct	Extrinsic Calibration
P4, 17. Oct	Lab 4: 3D range sensing
L12, 23. Oct	Review
30. Oct	Written Exam (preliminary)

Grading

- The grades on this course follow the Swedish system (U-G-VG)
- There is one written exam at the end of the course (U-G). To pass, you need to cover 60% of the points.
- Four labs will be graded at 25 points each. To pass, you need 60% of the points. For VG, you need 85% of the points.
- The final grade for the whole course is taken as the lab assignment grade, provided that you have passed the theoretical exam.
  - If you don't pass the theory part you fail the whole course (grade U)
  - If you at a later stage pass the theory re-exam, you will then get your lab grade (U-G-VG) as the full course grade.

Evaluation Criteria

In order to pass the theoretical section (a grade of G) a student should:

- Demonstrate knowledge of the principles of operation of the different types of sensors typical for mobile robots;
- Demonstrate knowledge of the different types of sensing technologies the sensors employ;
- be able to analyze the performance of different sensor types, identify sensor characteristics and potential sources of errors;
- demonstrate understanding of the way sensor data can be processed in order to remove noise;
- understand the theoretical frameworks behind sensor calibration.

Evaluation Criteria

In order to pass the practical section (a grade of G) a student should in addition:

- be able to configure and use a set of basic sensors in the context of a mobile robot inteligent control system;
- demonstrate practical ability to apply calibration methodology on physical sensor systems;
- demonstrate the ability to devise experiments and apply them to characterise sensor noise.

Evaluation Criteria

In order to pass the course with distinction (a grade of VG) a student should in addition:

- demonstrate ability to apply theoretical knowledge in order to solve practical problems in sensing and sensor data processing;
- demonstrate ability to analize the sources of noise in a sensor system and propose appropriate filtering and post-processing methods.

Lab Groups

Labs will be performed in groups of two. The groups are randomly assigned by the lab instructor at the door, and will change for each lab.

- Lab 1: Low-level arduino programming and serial communication
- Lab 2: Arduino motor control, ROS, and differential drives
- Lab 3: Range sensing: sonars and laser scanners
- Lab 4: Sensor data processing: point clouds and images

One report per group is to be submitted. We may ask for individual reports in special circumstances (e.g. we suspect someone is not contributing to the group work)!

Academic Integrity

- In accordance with the policies of Örebro University, any incidents suspected of cheating will be reported to the academic integrity board.
- Please always include references to others work in your written reports.
- It is OK to exchange ideas between lab groups, but do not copy code or explanations. If you have questions on the labs, the lab instructor should be your first point of contact.

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Definition and Classification

- Definition:
  a device that detects or measures a physical property and records, indicates, or otherwise responds to it.[1]
- In the context of robotics, several ways to classify different types of sensors based on:
  - physical properties sensed: range, appearance, absolute/relative position, speed, acceleration, force, torque, etc.
  - operating principle: active or passive.
  - physical measurement principle: acoustic or electromagnetic energy, time of flight, structured light, phase shift modulation, etc.

[1] source: Google

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Sensor Models and Noise

- A sensor is a device which measures some input signals a(t), in order to produce a sensor measurement y(t) of a particular physical property x(t).
- Depending on the type of sensor, the measurement y(t) can be deduced from a varying number and type of input signals a(t), which may or may not include x(t).
- The sensor measurements y(t) are typically modeled as:

$$\mathrm{y(t) = x(t)} + \nu\mathrm{(t)} + \eta\mathrm{(t)} \tag{1}$$

where:

  - ν(t) is systematic sensor noise
  - η(t) is random sensor noise, typically white Gaussian noise.
- Sensor calibration typically aims at reducing the systematic errors in sensor measurements.

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Sensor Drivers and I/O

- In order to receive sensor information and set parameters, most manufacturers provide software drivers.
- Depending on the sensor, several types of hardware interfaces to connect to the PC, e.g.:
  - Serial
  - USB
  - CAN Bus
  - Ethernet
- Regardless of the interface, sensors typically talk to the PC following custom protocols.
- If you have to write your own driver, best place to start is the sensor data sheet.

Sensor Data Processing

- In many applications, sensor data has to be pre-processed before use.
- Common procedures include:
  - Filtering of noisy measurements
  - Removal of error measurements or outliers
  - Fusion with other sensing modalities
- These procedures often require knowledge of the specifics of the sensor and can make a huge difference in the performance of higher-level, sensor-agnostic algorithms.

Actuators

- Actuators are the dual of sensors in robotics: they offer the means for the robot system to act upon the environment.
- Robots by definition require actuators (note not sensors)
- Most robots use standard DC motors: brushless or stepper motors, connected to custom mechanical systems.
- ... but there are many other types of actuators (hydraulic, pneumatic, etc.)

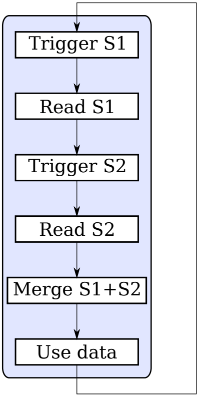
Using Actuators: Control

- Actuators are usually coupled with specific sensors in order to move the robot in a controlled fashion.
- Sensors are key in solving the actuator control problem, as they provide a feedback signal.
- Using sensor feedback and forward calculation of the expected action result, control algorithms can measure the control error.
- There is a large research field that deals with minimizing the control error and achieving “nice” motion. We will briefly discuss some basics of control in the next lectures.

Outline

Synchronous and Asynchronous Operation

- Robotic systems often need to read data from multiple sensors at varying rates.
- Synchronous operation and monolithic architectures do not scale well and are almost never used.
- Sensor information is usually acquired asynchronous from data processing.
- Which poses challenges in synchronization and architectures.



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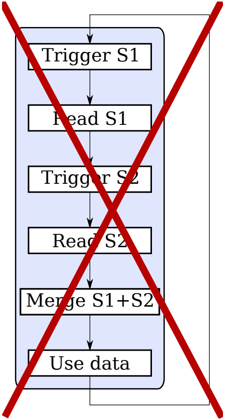

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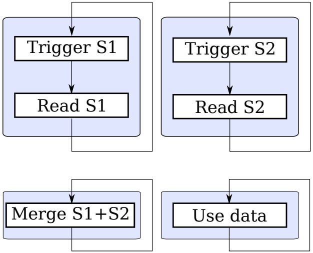

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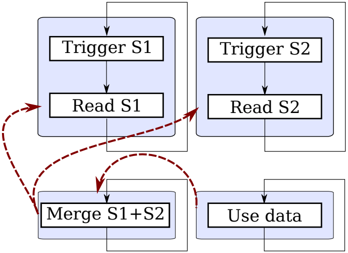
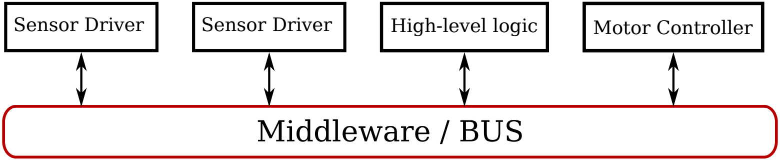


Middleware

- Coding sensor processing architectures from scratch can be difficult to get right.
- Standardized middleware layers that deal deal with low-level message passing and synchronization are one popular solution.

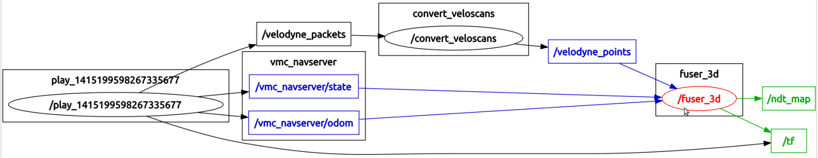


Pipelines

- Pipelines are a common means of processing sensor data.
- Each sensor node publishes data as it becomes available.
- Subsequent nodes in the pipeline process the data and publish their results to the next node.

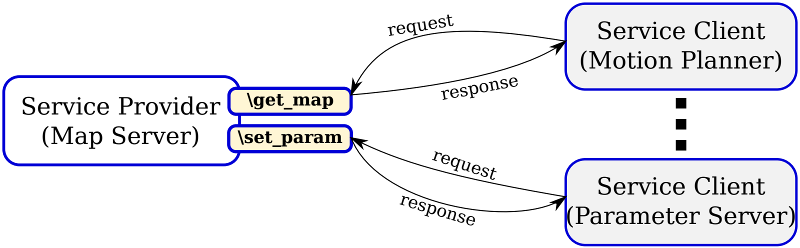
Publishers and Subscribers

- A related paradigm is that of publishers and subscribers.
- Every node publishes data and results as they become available.
- Any number of client nodes can subscribe to the published topic and receive data.



Servers and Clients

- In some cases publisher/subscriber semantics are not efficient.
- ... e.g., a node computes a result based on some input data and returns the result.
- The common way to handle these situations is by providing services to the rest of the system.



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How to write a good lab report?

- First and foremost, always think before you write!
- If you have completed the steps for a given task, you have to verify that you did so correctly.
- In the report, you need to describe what you did, why you did it in this manner, and how you evaluated the end result.
- In some cases, you will need to also think of what are the implications of your results (and describe your reasoning).
- Use short and clear sentences.
- Organize your sentences and paragraphs logically.
- Be scientific. Do not guess, test.
- A lab report is in many ways a small scientific paper. Follow scientific writing guidelines, provide references, caption your figures, label your axes and use appropriate units.

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ROS basics

- How does ROS work? Cover topics, publishing / subscription, messages
- Do the beginner ROS tutorials when you have time `http://wiki.ros.org/ROS/Tutorials`

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