Multi-Sensor Data Fusion

Class 1: The Sensor Fusion Problem

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Digi-Key ELECTRONICS

This Week's Agenda

Monday	The Sensor Fusion Problem
Tuesday	Algorithms
Wednesday	Sensor Types
Thursday	Sensor Fusion
Friday	Applications

Course Description

The use of multiple, heterogeneous sensors is often necessary. This is the case in areas such as robot control, autonomous vehicles and military aviation. Different skills are required including electrical engineering, computer science and statistics. These systems can be complex and include many control theory concepts. In this class we will go over the problem, describe the types of algorithms and sensors used and finally will give some examples.

Today's Agenda

- Overview
- History
- Requirements
- Sensors
- Processing
- Conclusion/Next Class

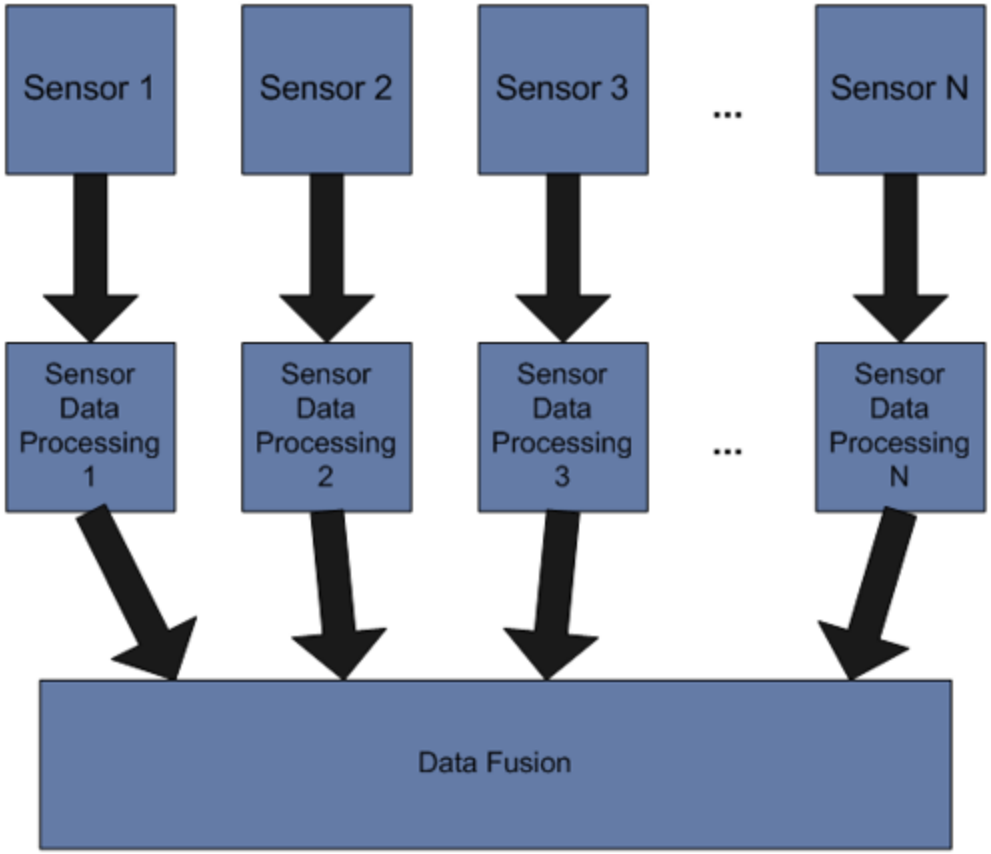
Overview

- First let's unpack the title of the Class
  - Multi-sensor: multiple homogeneous or heterogeneous sensors providing inputs from the environment
  - Data: information provided by the sensors, processed to provide estimates of the parameters of the system model
  - Fusion: synthesis for a robust description of a process or environment

Overview

- The “data fusion” part, and techniques, do not only apply to sensors. Much of the theoretical background, which we will discuss tomorrow, was developed in the field of probability and statistics without reference to sensor fusion.
- It is the modeling of the system that brings in the sensor aspects to the solution.

Overview


Sensor 1
Sensor 2
Sensor 3
...
Sensor N
Sensor Data Processing 1
Sensor Data Processing 2
Sensor Data Processing 3
...
Sensor Data Processing N
Data Fusion

Overview

- The goal of Multi-Sensor Data Fusion (MSDF) is to build up a model of the external world in order to perform some function with an automated system, such as an autonomous vehicle, robot or other mechatronic device.
- Many of the techniques developed can be used for completely computer-based applications, which do not manipulate the physical world. We will not be covering these.

History

- The modern field of MSDF dates back to the 1980s
- Many early applications were in the aerospace and defense sector (my first exposure)
- Other early sectors include:
  - Complex industrial machinery monitoring
  - Smart buildings
  - Medical diagnosis
- These tended to be fields with high budgets and/or costly devices

History

- There were many IEEE conferences in the 1980s on both the sensors and the processing of those sensors, mainly stressing the aerospace and defense sector
  - Many new sensors were being introduced
  - New processors and architectures
  - Lots of new algorithms and refinements of complex statistical techniques

History

- Some examples:
  - Aircraft autopilots
    - Terrain following autopilot (nap of the earth)
  - Rovers for use on distant worlds (moon, Mars)
  - Drones (Predator)
- Self driving cars were first developed in the 1970 (Tsukuba in Japan)
  - Limited in speed (20 MPH)
  - Used cameras
  - In the 21st century this has evolved rapidly

Requirements

- Requirements can be thought of in two dimensions
  - First follows the task to be performed
    - This drives the type of world model used
    - Determines what algorithms are most appropriate
  - Second is the mix of sensors and processing approaches to be used
    - Sensors may be a baseline (i.e., imposed) or may be a blank canvas
    - Processing architecture can be centralized, distributed or a mix

Requirements

- Each of these areas impinge on the other and have important constraints
  - Process rate is a major consideration
    - Autonomous vehicles, aircraft, etc. will each have high rates of processing, sensor bandwidth and other complexities
    - The environment is another major factor. Clutter and variability are often issues
      - We have had “self driving” aircraft for a while (low clutter environment)
      - Self driving cars still present challenges (high clutter environment)

Requirements

- Based on the environment we may choose sensors in many ways
  - Multiple types of sensors
  - Different numbers of each type
  - Distribution of the sensors around the vehicle or device
  - Cost of sensors
    - This is a constantly moving target. Sensor types, resolution and processing capabilities are always improving
    - Need flexible architectures to be able to incorporate new sensors as they become available

Requirements

- Once the world model and sensors are chosen, the ability to process this information is critical
- Application and environment will drive these decisions
  - A moon rover cannot use ground-based processing because of communication delays
  - An industrial robot or plant monitoring system can

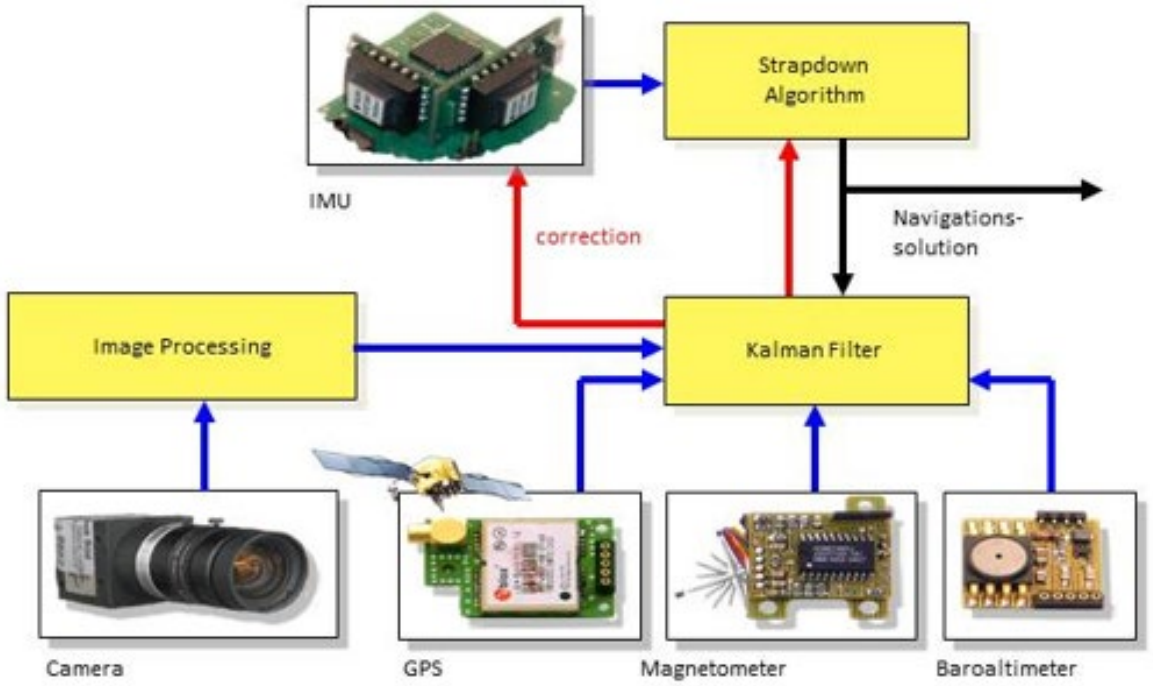
Requirements

- Several disciplines are required to bring all this together
  - Engineers
    - Systems
    - Electrical, often specializing in specific sensor types
    - Computer
    - Software
  - Statisticians
    - As we shall see tomorrow, the algorithms used are based on complex statistical models

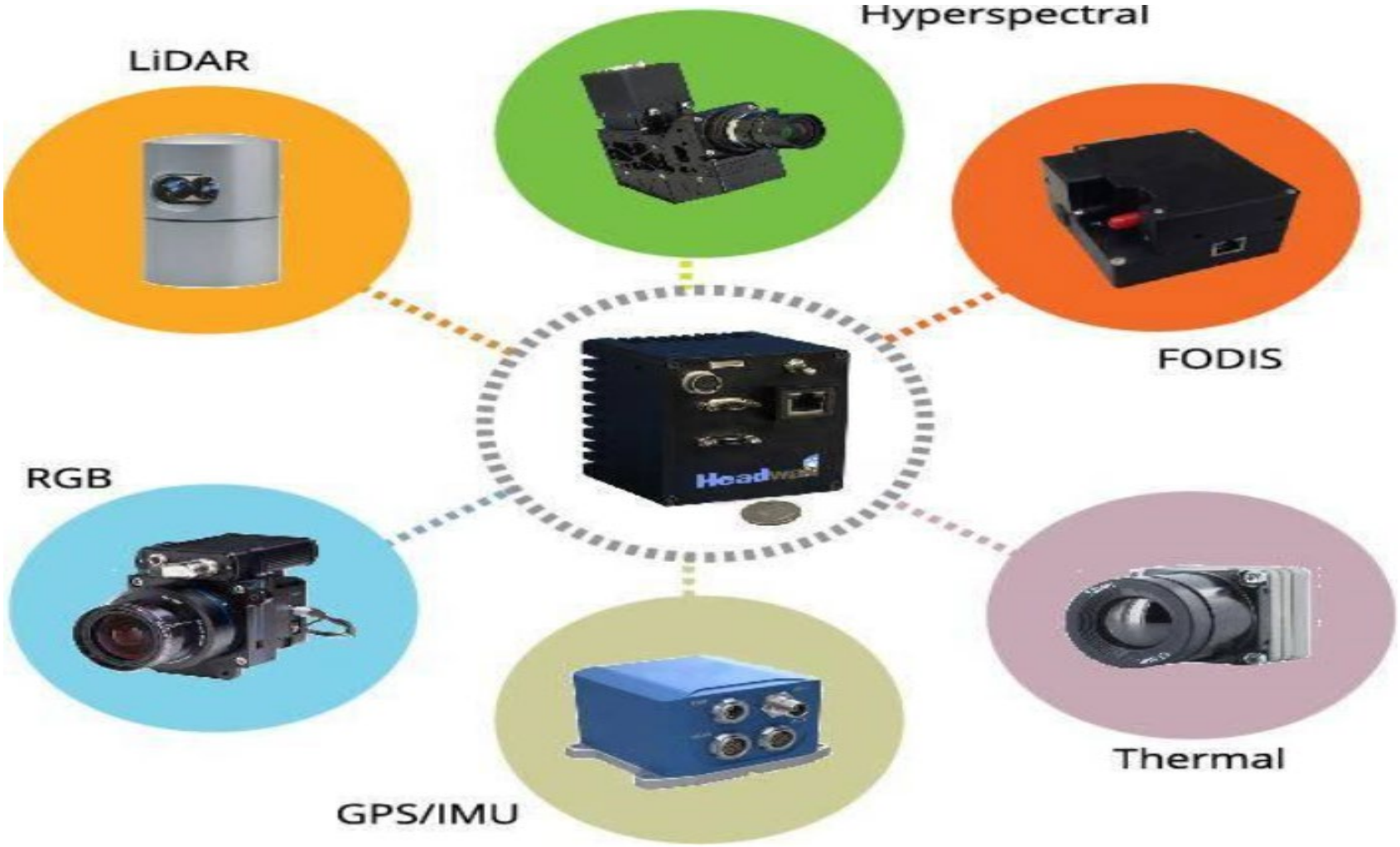
Sensors

- Sensors come in many types, each bringing its own requirements and challenges
- Disparate sensors typically operate at different rates and resolutions
  - This is where much of the complexity comes in
- Placement of sensors is also a consideration
- Coordination between the various disciplines is of primary importance in this regard

Sensors


IMU
Strapdown Algorithm
correction
Navigations-solution
Image Processing
Kalman Filter
Camera
GPS
Magnetometer
Baroaltimeter

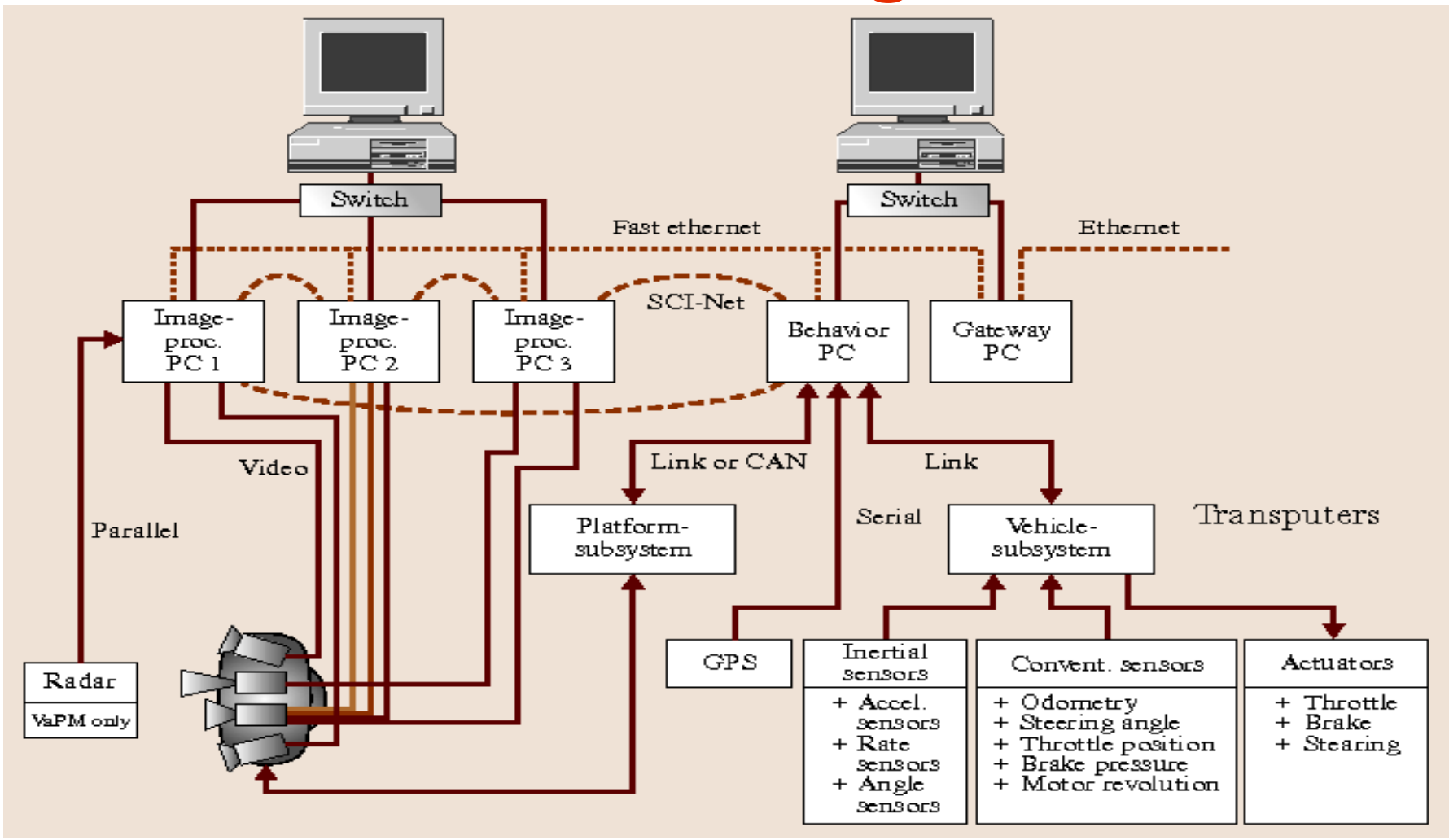
Sensors



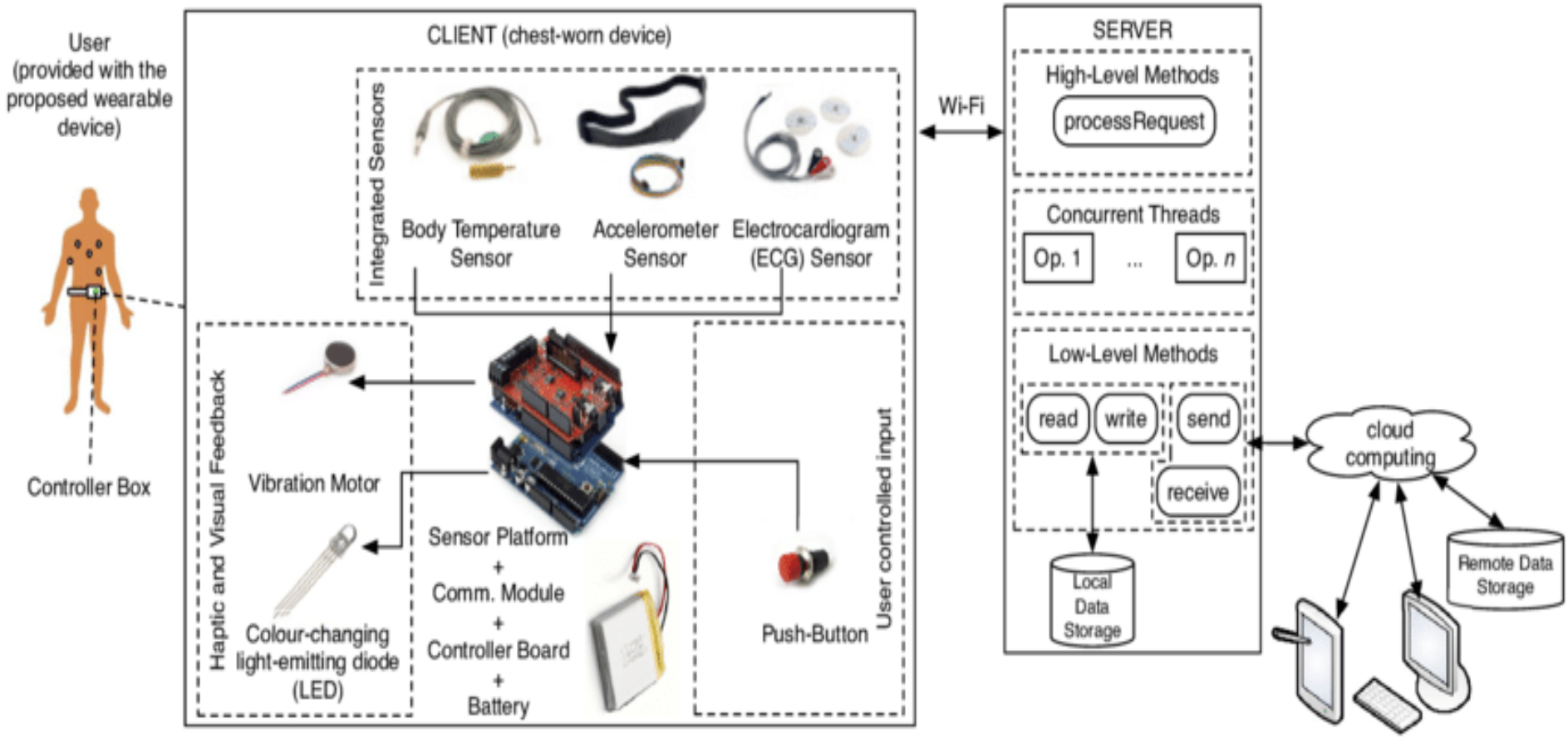
Processing

- Processing of the sensor input and integrating this into a model can be done in many ways
  - Sensors can be “smart” or basic
  - Based on the model used, different approaches can be used to produce the desired output
  - Sometimes sensors can be grouped
  - The number of stages of integration can vary
  - Fusion processing is generally centralized producing the model which can then be used to perform the desired action

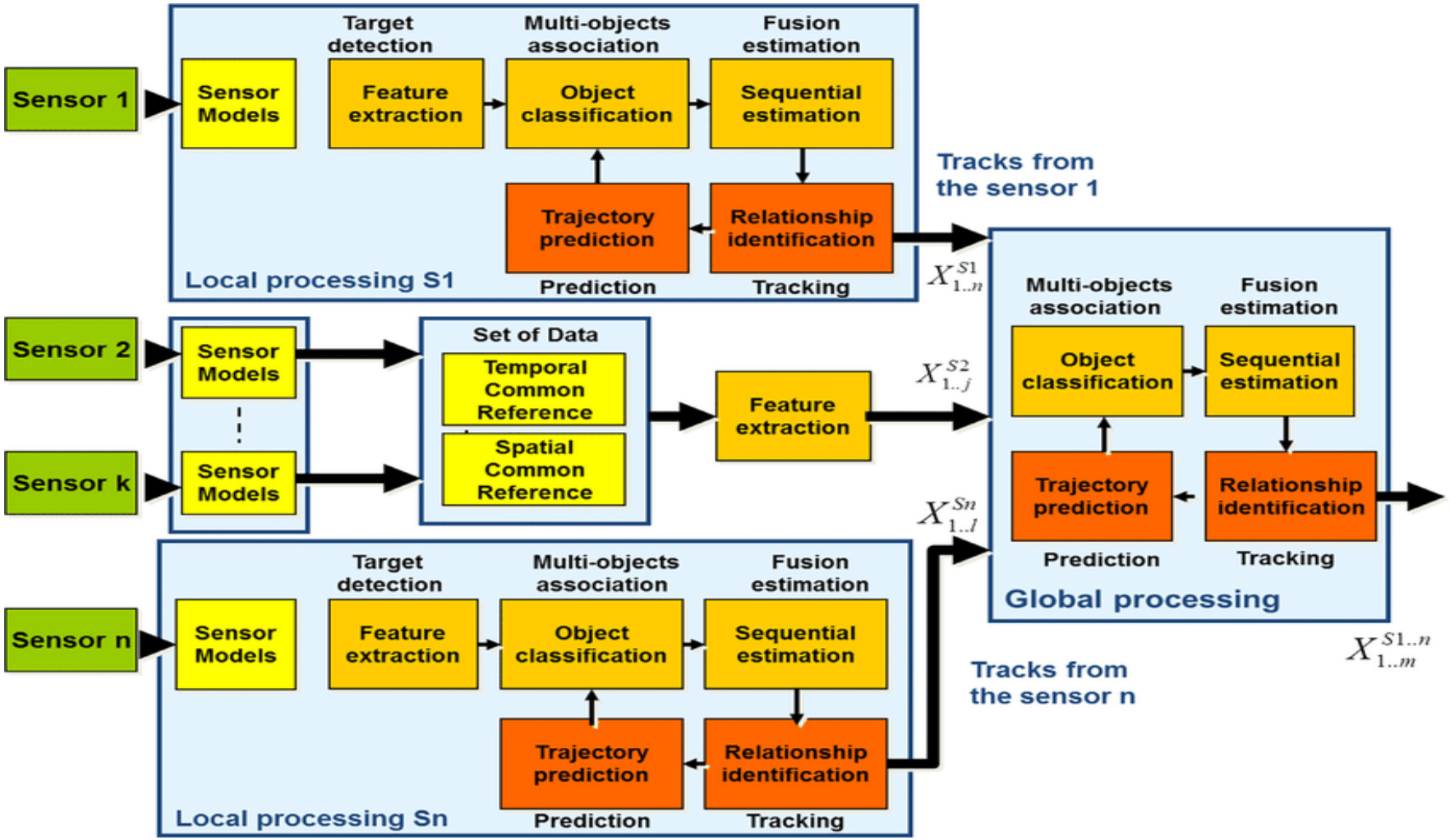
Processing


Switch
Switch
Fast ethernet
Ethernet
SCI-Net
Image-proc. PC 1
Image-proc. PC 2
Image-proc. PC 3
Behavior PC
Gateway PC
Video
Parallel
Link or CAN
Link
Serial
Transputers
Platform-subsystem
Vehicle-subsystem
Radar
VaPM only
GPS
Inertial sensors
+ Accel. sensors
+ Rate sensors
+ Angle sensors
Convent. sensors
+ Odometry
+ Steering angle
+ Throttle position
+ Brake pressure
+ Motor revolution
Actuators
+ Throttle
+ Brake
+ Stearing

Processing


User
(provided with the proposed wearable device)
Controller Box
CLIENT (chest-worn device)
Integrated Sensors
Body Temperature Sensor
Accelerometer Sensor
Electrocardiogram (ECG) Sensor
Haptic and Visual Feedback
Vibration Motor
Colour-changing light-emitting diode (LED)
Sensor Platform
+
Comm. Module
+
Controller Board
+
Battery
User controlled input
Push-Button
Wi-Fi
SERVER
High-Level Methods
processRequest
Concurrent Threads
Op. 1
...
Op. n
Low-Level Methods
read
write
send
receive
Local Data Storage
cloud computing
Remote Data Storage

Processing


Sensor 1
Sensor Models
Target detection
Feature extraction
Multi-objects association
Object classification
Fusion estimation
Sequential estimation
Trajectory prediction
Relationship identification
Prediction
Tracking
Local processing S1
Tracks from the sensor 1
Sensor 2
Sensor k
Sensor Models
Set of Data
Temporal Common Reference
Spatial Common Reference
Feature extraction
Sensor n
Local processing Sn
Multi-objects association
Fusion estimation
Object classification
Sequential estimation
Trajectory prediction
Relationship identification
Prediction
Tracking
Global processing
Tracks from the sensor n

Conclusion/Next Class

- In this class we have introduced the general MSDF problem and history
- We have laid out the general requirements
- We have reviewed some aspects of sensors and processing, which will be looked at in greater detail in future classes
- Tomorrow we will dive into the algorithms used in this area