Tagless indoor human localization and identification using capacitive sensors

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- Rationale for long-range capacitive sensing
- Measurement of small capacitance variations
- Human localization using ML classifiers
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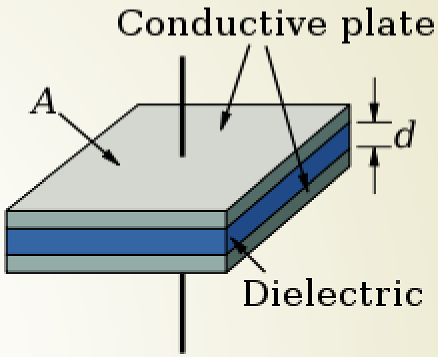
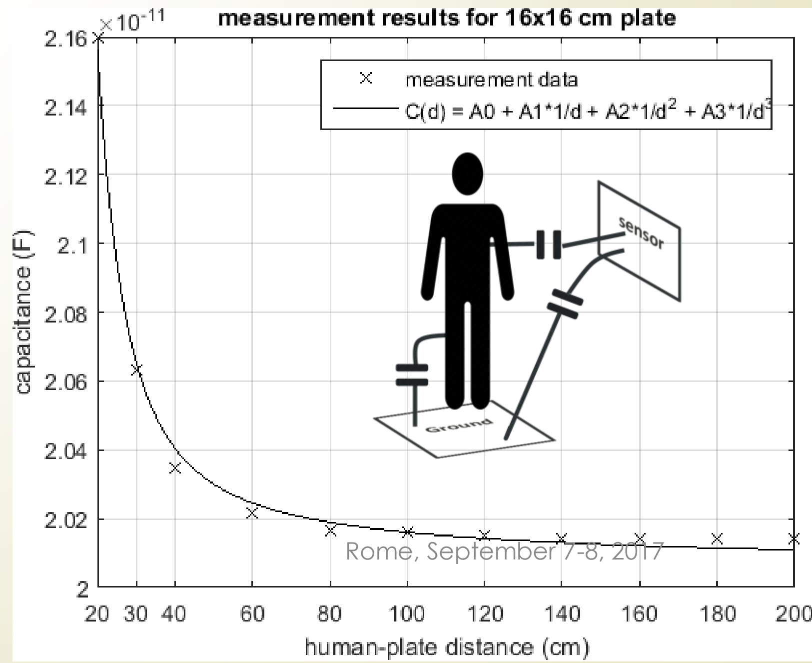
Why long-range indoor capacitive sensing?

- Indoor human localization and identification can enable many automation and monitoring apps
- Long-range load-mode capacitive sensors are small, inexpensive, easy to install and operate
- Generally low accuracy and low range
- Low noise measurement techniques ($C \sim A / d^{2 \div 3}$)
- Sensor data post-processing:
  - Improve SNR ($\Delta C < 0.01\%$)
  - Infer human location and behavior

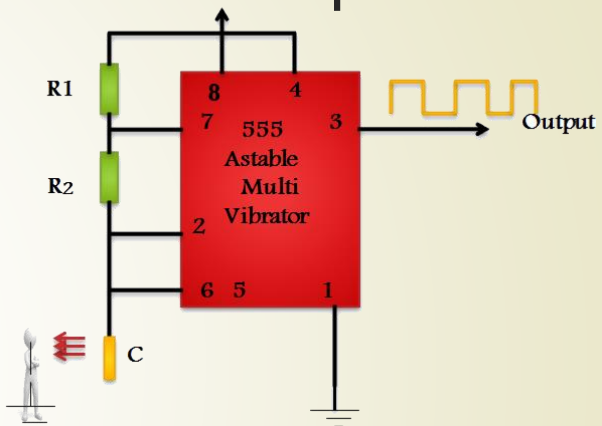
Measurement challenges



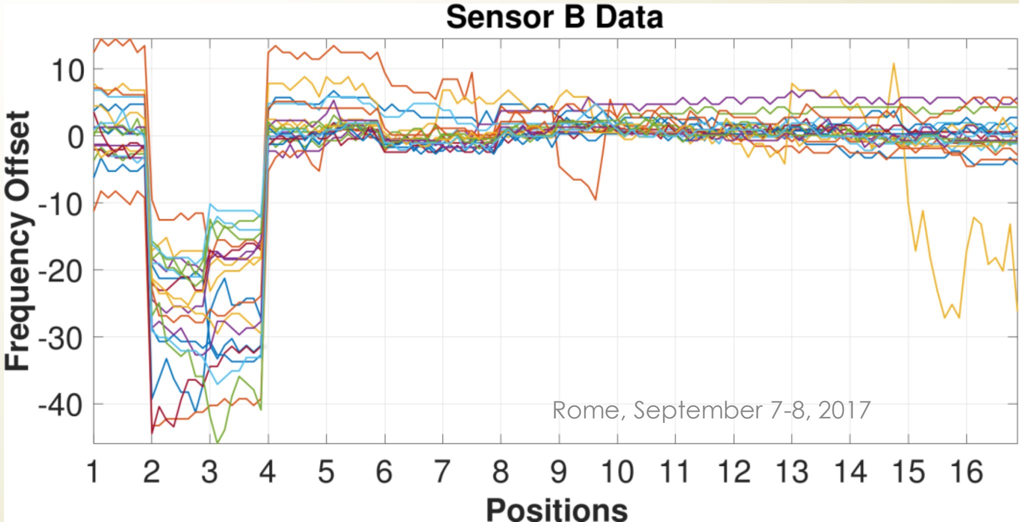
- Planar capacitors with $\sqrt{A} >> d$
  - $C = \varepsilon A / d$
- Load-mode capacitors with $d >> \sqrt{A}$
  - $C \sim A / d^{2 \div 3}$
- d (meters) >> $\sqrt{A}$ (tenths of cm):
  - Very low ΔC (< 0.01%)
  - Very high measurement sensitivity
  - Low noise sensitivity
  - Good noise rejection



Base band measurement: charge-to-voltage => freq.

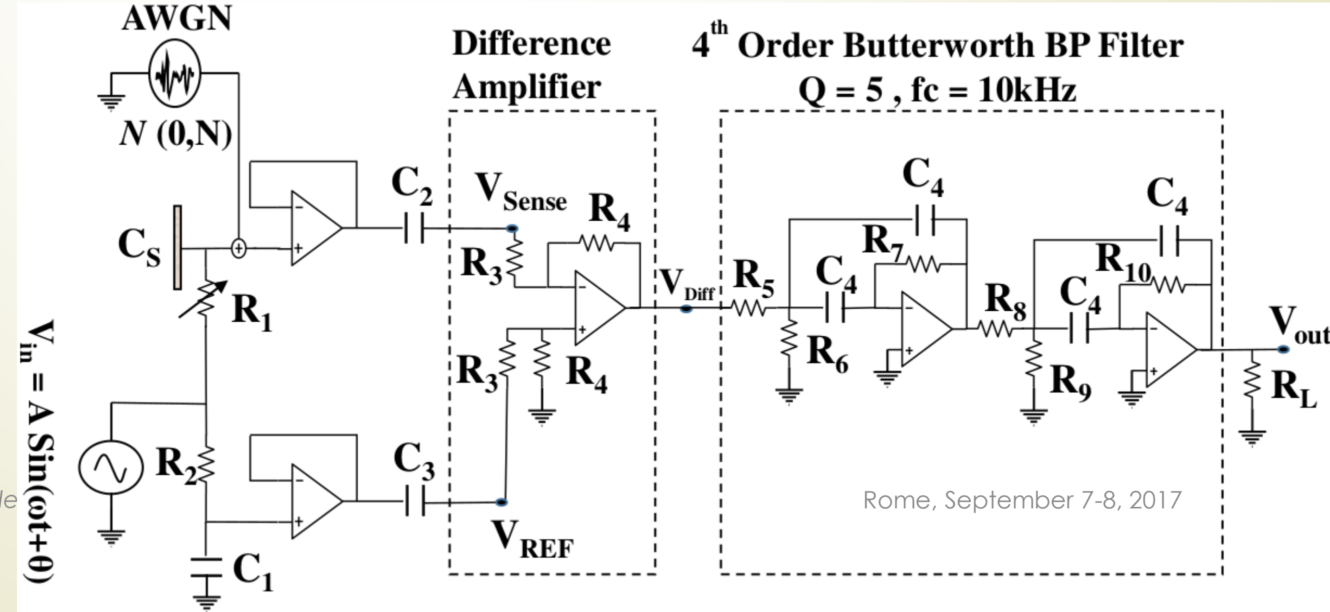


- C = Q / V
  - Control Q flow, set V thresholds
  - Measure f ~ 1 / time-to-V threshold
- Simple, cheap, low-power
- Low C, low I for kHz-range f (lower quantization noise)
  - Very high impedance input
  - Susceptible to EM noise (V noise => f jitter)
  - Difficult noise filtering
- Low SNR overall



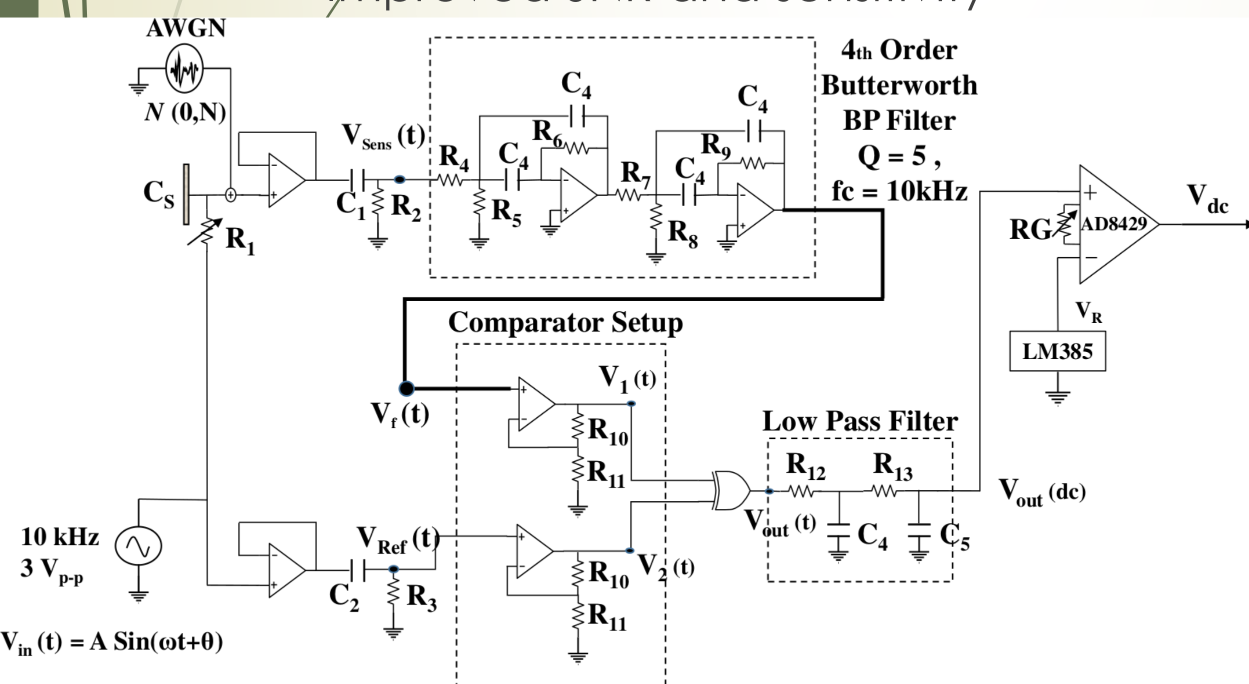
Carrier modulation: phase and amplitude

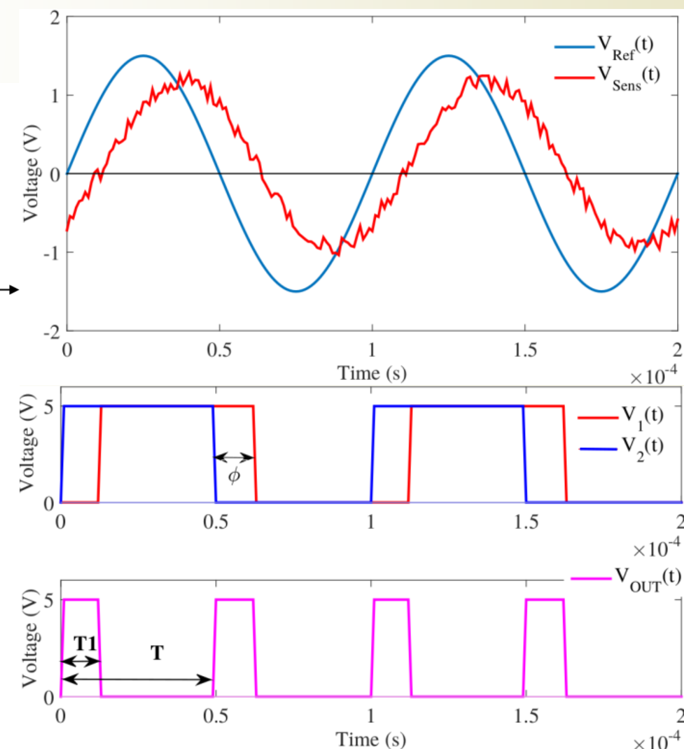
- V_{diff} correlated to carrier amplitude and phase shifts due to X_{Cs} changes
- Effective carrier noise filtering (stable known frequency)
- Output signal can be amplified before measurement (lower quantization noise)
- Overall improved SNR and sensitivity



Carrier modulation: phase

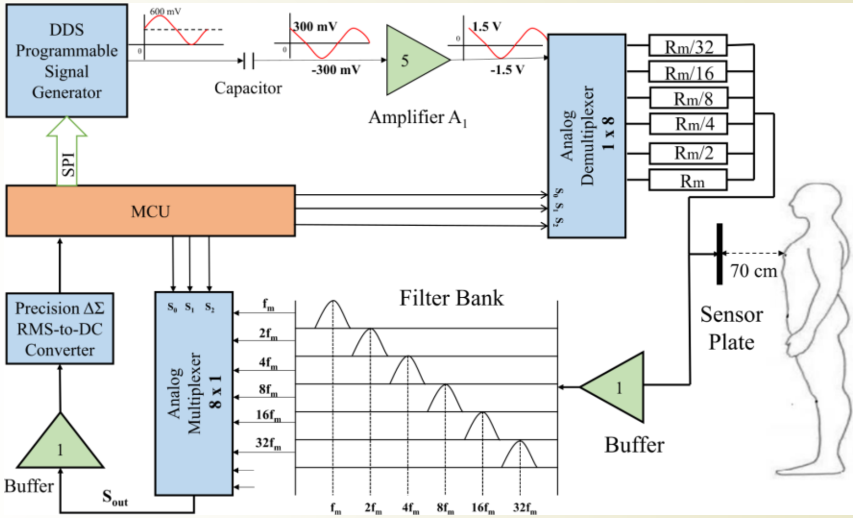
- Vdc correlated to carrier phase shifts due to X_{Cs} changes
- Carrier noise can be filtered well
- Output can be amplified
- Improved SNR and sensitivity

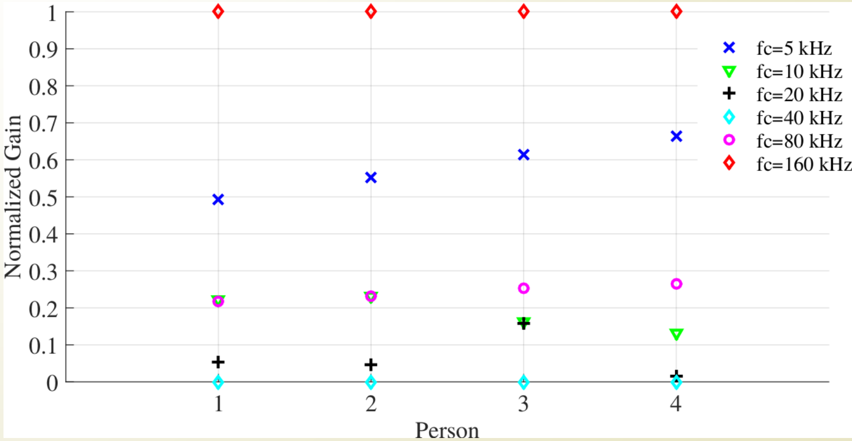




Human identification

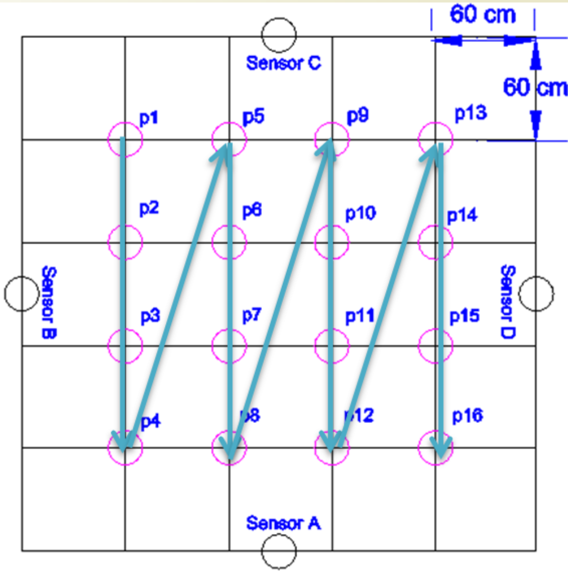
- Measure the body-sensor capacity at several frequencies at (almost) the same time
- Capacity-frequency dependency pattern depends on body properties (tissue ratios, shape, …)
- Distinct patterns can identify persons from limited pool
- Monitor passage through doors

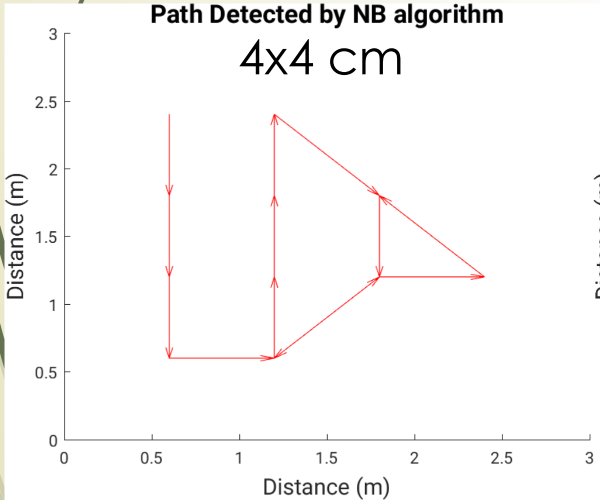


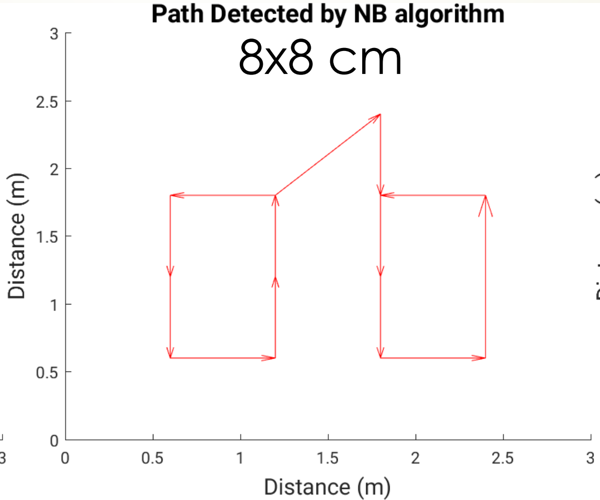


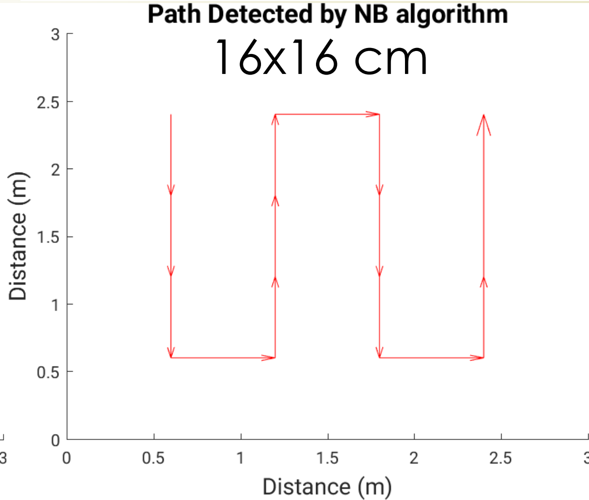
Localization using machine learning classification

- Room localization experiment using ML classification and the "noisy" sensors
  - Train k-NN, Naïve Bayes, SVN to classify 16 room locations using sensors of different sizes
  - Test algorithms classification accuracy
- Naïve Bayes performed best, especially for the largest sensor size (16 x 16 cm)



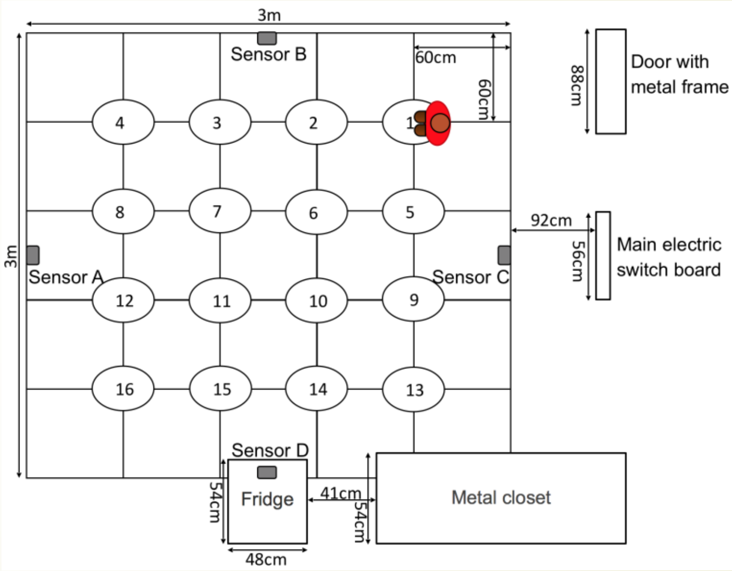




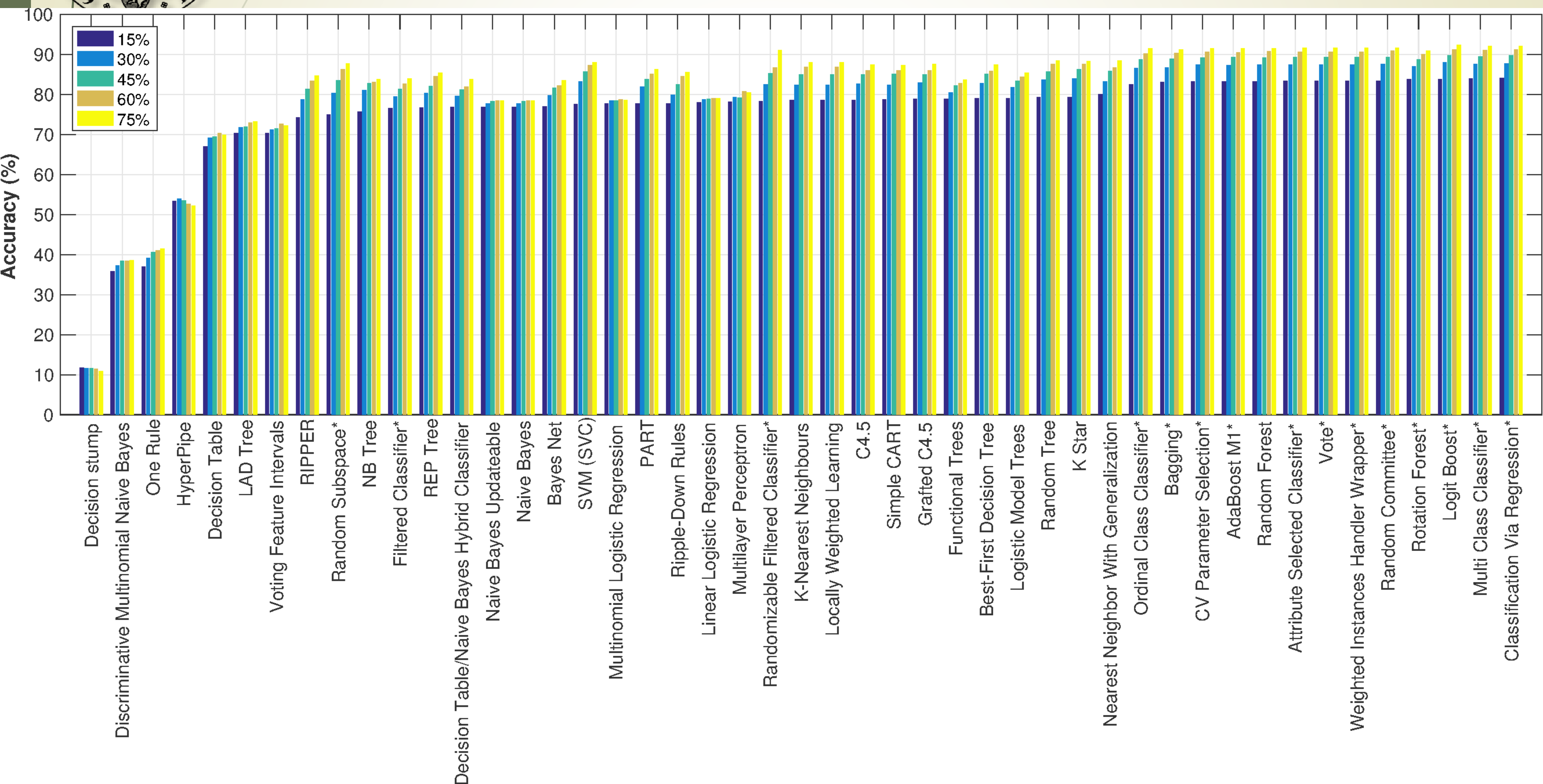


Performance of machine learning localization (1)

- Same room, same sensors, but:
  - Data acquired using different body angles
  - Acquisitions weeks or months apart
- Tested performance of most (48) Weka collection algorithms
  - Training using with different set sizes
  - Testing with unseen data sets
- Performance measurement
  - Accuracy, error, precision, recall, train effort, classification effort, memory requirements



Performance of machine learning localization (2)



Using advanced machine learning algorithms

- Classification (1 out of 16 locations) has a significant quantization error (15cm on average with 60cm grid) and may not be suitable for all applications
- Can use neural networks to directly convert sensor outputs to (x,y) location within room, with improved precision
- Recurrent neural networks (with feedback) can also reduce the need for filtering (the network "learns" the expected speed range of the person moving around the room)
- However, NNs and RNNs have much higher computational complexity: 100K neurons are required to achieve a mean distance error of 10cm

Energy requirements of machine learning algorithms

- The computational load of a neural network evaluation for human localization can easily be 1MFLOP
- The requirements to track millions of people exceed 1 ExaFLOP
- Energy requirements are becoming the bottleneck for large data centers, hence FPGAs are being used to accelerate computationally intensive workloads
- The ECOSCALE H2020 project n. 671632 is aimed at enabling the use of FPGAs in data centers
- The machine learning algorithms for human localization using capacitive sensors will be used as a design driver in ECOSCALE

Conclusions

- Capacitive sensing may provide the low cost indoor sensing needed to enable many smart applications
- Combined with other sensing techniques, it may contribute to define a platform that enables to *install apps on the home*
- Needs effective techniques to reject and reduce noise
- Intensive data processing may improve performance
  - Low power analog and digital processors (µP, FPGA) and communication essential for low exploitation costs

Thank you.

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