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Reject-optional LVQ-based Two-level Classifier to Improve Reliability in Footstep Identification

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Outline

- Introduction
- EMFi-Floor
- Footstep Data
- Identification Methods
- Experimental Results
- Conclusions

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Introduction

- What we have done?
  - Experiments on recognizing walkers from the measurements achieved with a pressure sensitive floor
    - A 100 square meter pressure sensitive floor was used
    - Test classifications included footsteps from eleven walkers
    - A Two-level identification method proposed
- Identification methods
  - The Reject-optional Learning Vector Quantization
    - Based on standard LVQ classifier
    - Reject-option is determined to detect unreliable footsteps and reduce classification error

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Introduction (2)

- Two-level identification system
  - Detecting 3 consecutive footsteps, when person enters a smart room
  - Two-level identification:
    - First level performs reject-optional LVQ classification for a single footstep
    - Second level combines the sequence of three pre-classified footsteps to make joint decision
  - Identifying eleven walkers overall success rate was 90% with 20% rejection rate

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Introduction (3)

- Aim
  - A part of research on intelligent environments: to learn and to react to behaviour of occupants
    - Hidden sensory system provides a natural way to use personal profile
  - Applications
    - Monitoring hazardous situations
    - Surveillance systems
    - Helping child care
  - Adaptive online identification system
    - Correcting automatically small changes
    - Detecting new persons and learning their behaviour

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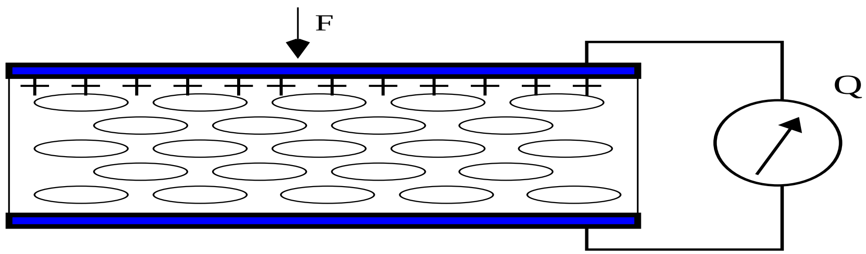
EMFi-Floor

- ElectroMechanical Film (EMFi)
  - A thin, flexible, lowprice electret material
  - Consists of cellular biaxially oriented polypropylene film coated with metal electrodes
  - It is possible to store a large permanent charge in the film by corona method using electric fields
  - An external force affecting on the EMFi's surface causes a change in the films thickness resulting a charge between the conductive metal layers
    - This charge can be detected as a voltage, which describes the changes in the pressure affecting the floor



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EMFi-Floor (2)

- Floor Setting
  - In our research laboratory EMFi-material is placed under the normal flooring
  - Consists 30 vertical and 34 horizontal EMFi-sensor stripes, 30 cm wide each
  - Advantages
    - Number of wires
    - Number of channels to process
  - Disadvantages
    - Tracking multiple persons
    - To get “good quality” footsteps for identification

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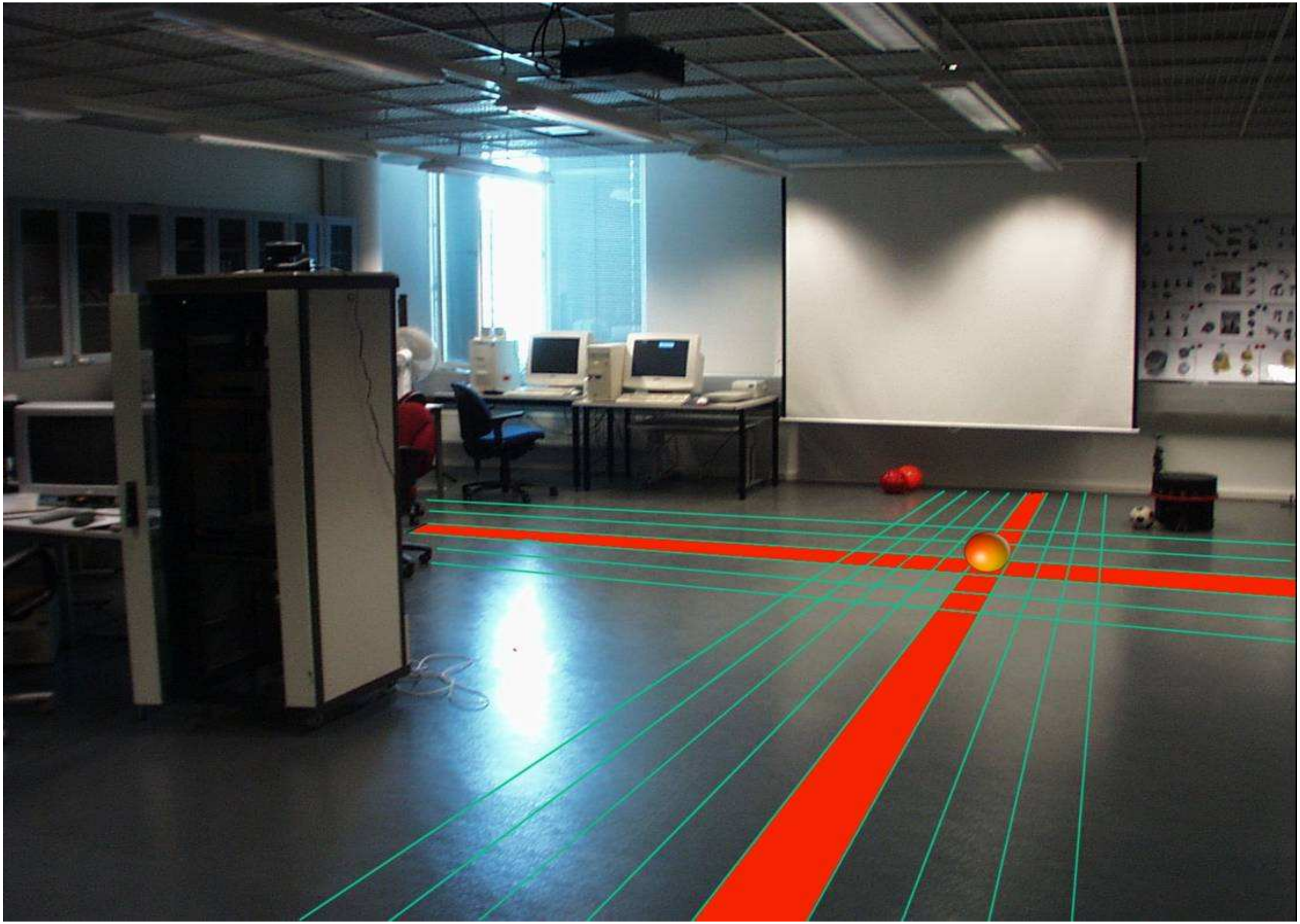
EMFi-Floor (3)



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EMFi-floor(4)

- EMFi Data
  - Each 64 stripes produces continuous signal
  - Streamed into a PC from where the data can be analysed in order to detect and recognize the pressure events
  - The analogous signal is processed with National Instruments data acquisition -card (PCI-6033E), sampling rate can be chosen between 0.1 - 1.54 kHz
    - 100 Hz sampling rate is used in these experiments

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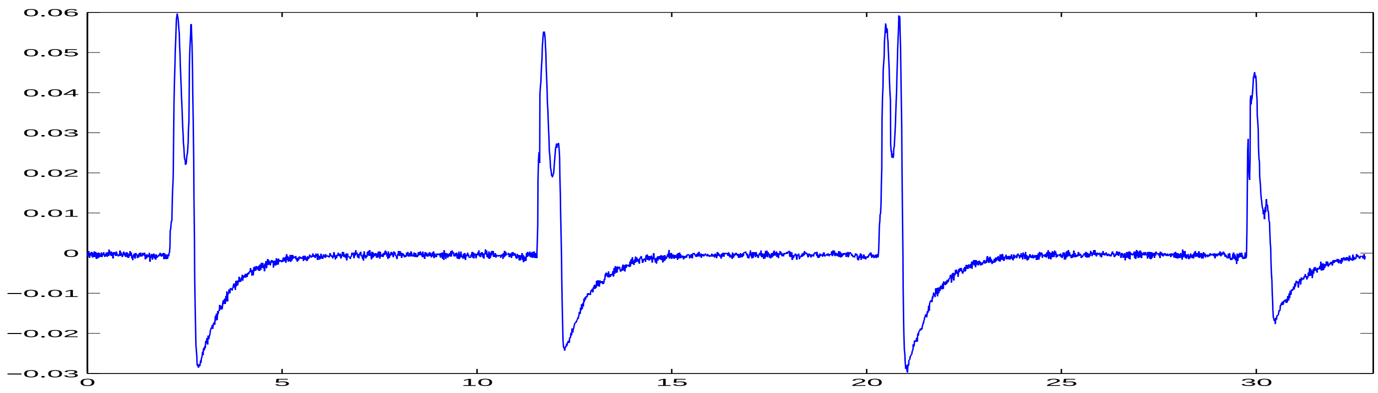
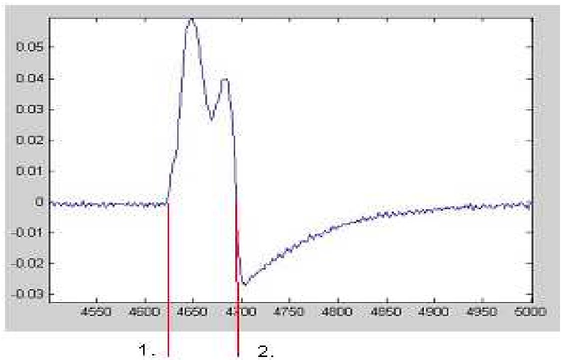
EMFi-floor (5)

- Raw data



- Segmented footstep



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Footstep Data

- Collecting data
  - Footstep data was recorded from eleven different persons
  - The subjects stepped on one particular stripe
  - Collected data contained about 40 steps/person, including steps from both feet
- Pre-processing
  - Finding good-quality steps from noisy data
    - A raw segmentation was made with edge detection using FIR median hybrid filter, convolution, and thresholding
    - Footstep parts from adjacent channels were summed

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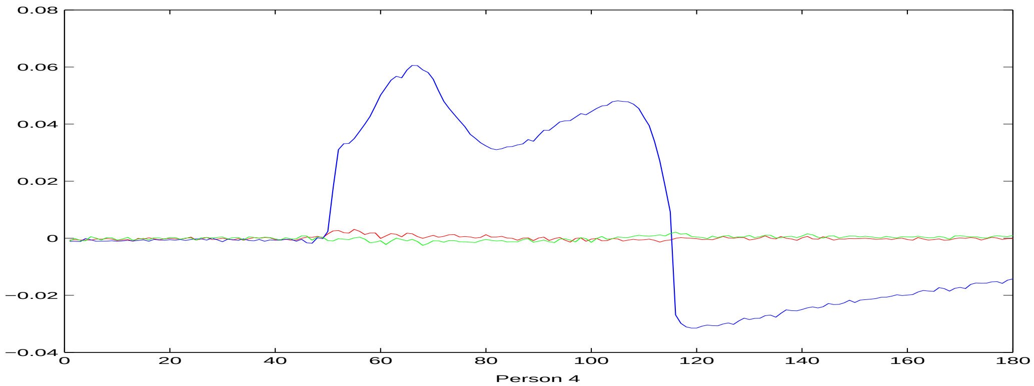
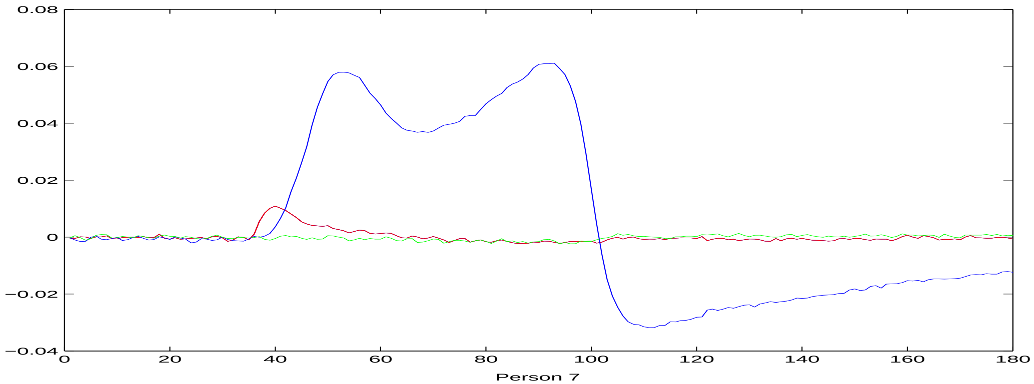
Footstep Data (2)

- A “good quality” footstep has hit on the center of one stripes



- A small part of footstep has hit on adjacent stripe



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Footstep Data (3)

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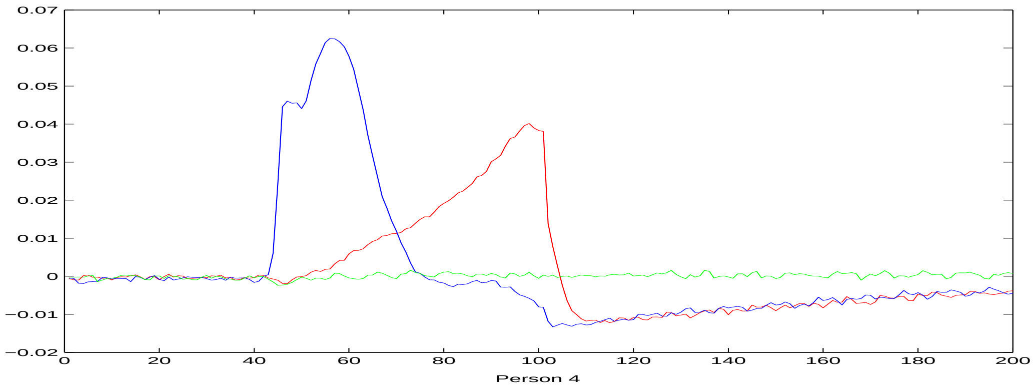
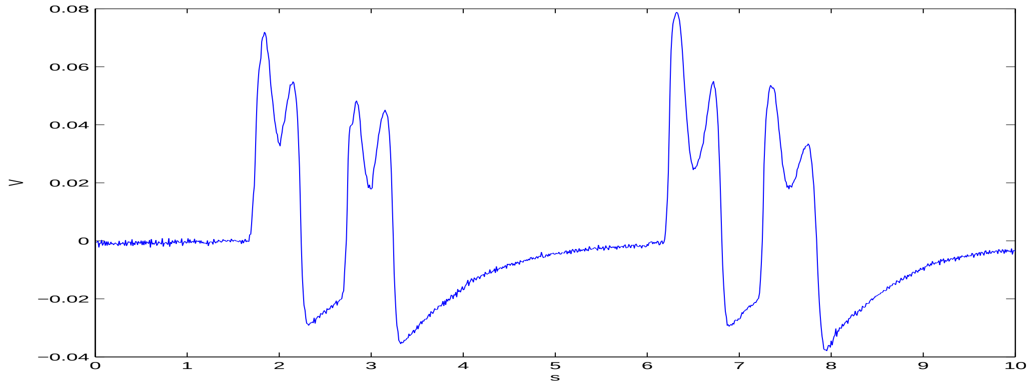
- A footstep has hit the crossing of two stripes



- Several footsteps have hit along one stripe



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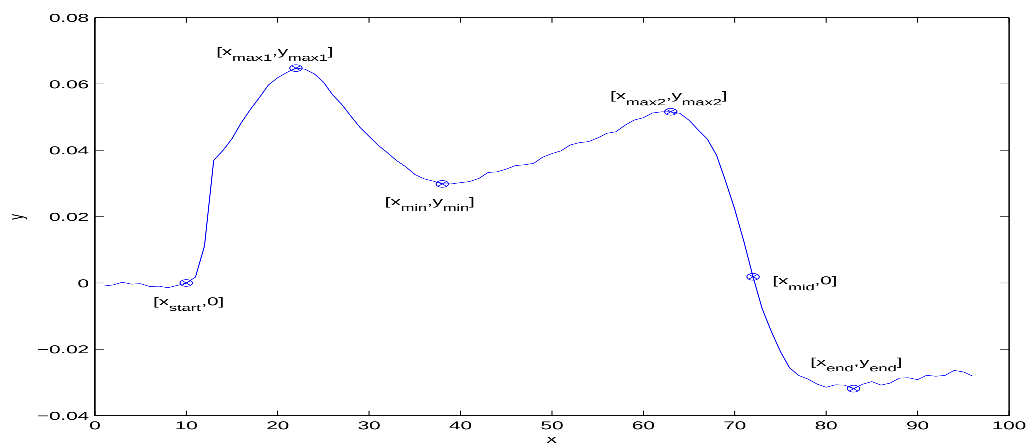
Footstep Data (4)

- Feature selection
  - Each step was divided in two sections: The heel strike and the toe-off peak
  - Several features was calculated from both spatial and frequency domain
  - 13 features was selected for classification



Identification Methods

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- Learning Vector Quantization (LVQ)
  - A well known statistical distance based classification method
  - Based on piecewise linear class boundaries, which are determined by supervised learning
- LVQ classification
  - Classification is made with a codebook, which contains prototype vectors labeled for each classes
  - Learning algorithm iteratively minimizes the rate of misclassification error by updating the codebook vectors
  - The unknown sample is classified to the closest codebook vector using Euclidean distance

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Identification Methods (2)

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- A basic training algorithm LVQ1:

$$(1) \qquad m_j(t+1) = m_j(t) + \alpha(t)[c(t) - m_j(t)],$$

if c and m_j belong to the same class.

$$(2) \qquad m_j(t+1) = m_j(t) - \alpha(t)[c(t) - m_j(t)],$$

if c and m_j belong to different classes.

$$(3) \qquad m_i(t+1) = m_i(t), \text{for } i \neq j.$$

- m is codebook vector, c is training sample, and α is learning rate

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Identification Methods (3)

- Reject option
  - Effectiveness function

$$P = C_c(R_c - R_c^0) - C_e(R_e - R_e^0) - C_r R_r. \tag{4}$$

  - Reliability evaluators for LVQ

$$\Psi_a = \begin{cases} 1 - \frac{O_{WIN}}{O_{max}}, & \text{if } O_{WIN} \leq O_{max} \\ 0, & \text{otherwise.} \end{cases} \tag{5}$$

$$\Psi_b = 1 - \frac{O_{WIN}}{O_{2WIN}}. \tag{6}$$

Identification Methods (4)

- Determination of reject thresholds

$$C_N D_e(\sigma) - D_c(\sigma) = 0.$$

  - D_c and D_e are occurrence densities
  - $C_N = (C_e - C_r)/(C_r + C_c)$ is normalized cost

1. The training set is classified with a 0-reject classifier and then split into the subsets S_c of correctly classified samples and the subset S_e of misclassified samples.
2. The values of the reliability evaluators Ψ_a and Ψ_b are determined for each sample in the sets S_c and S_e. Then, the occurrence density functions $D_c(\Psi_a)$, $D_c(\Psi_b)$, $D_e(\Psi_a)$, and $D_e(\Psi_b)$ are calculated.
3. The values of σ_a and σ_b, satisfying the P's derivate to be zero, are calculated.
4. The values of σ_a and σ_b from Step 3. maximizing effectiviness function P are chosen as rejection thresholds.

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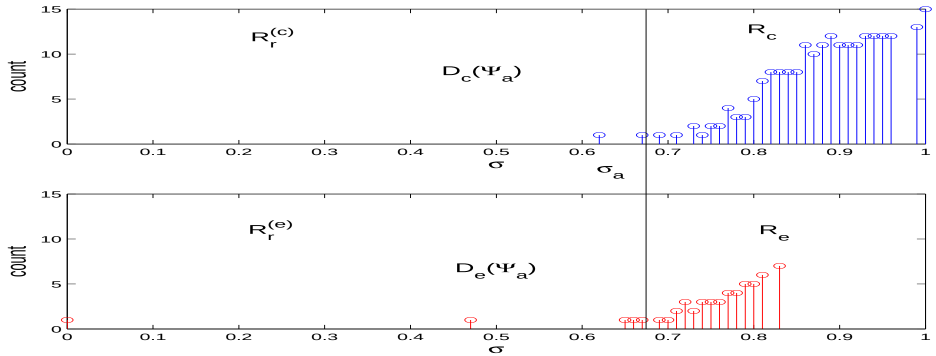
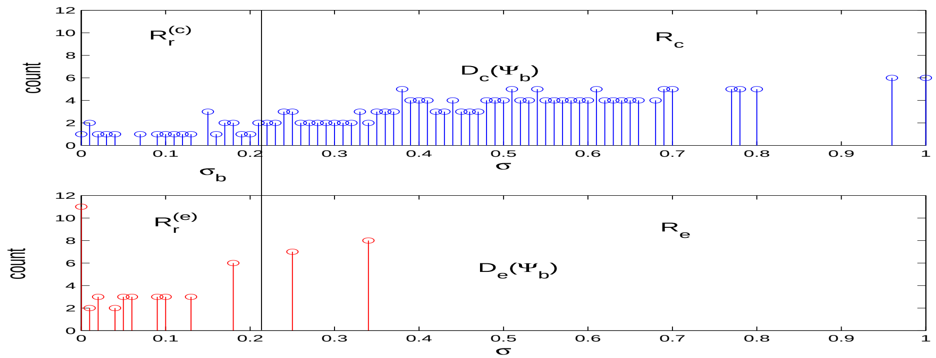
Identification Methods (5)

- Samples below σ_a are rejected being too far from the class boundaries

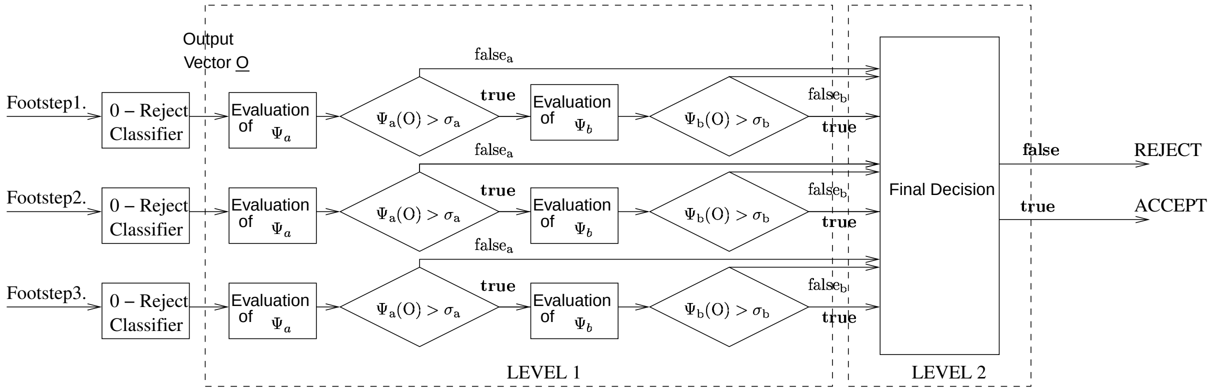


- Samples below σ_b are rejected from the overlapping region of two or more classes



Identification Methods (6)

- Two-level identification system:



- LEVEL 1: Identifies or rejects a single footstep
- LEVEL 2: Identifies or rejects a sequence of three independent footstep based on the knowledge from the first level

Identification Methods (7)

- Final decision rules:
- REJECT
  1. If a majority of the three samples are rejected by Ψ_a.
  2. If one of the three samples is rejected by Ψ_a and another one is rejected by Ψ_b.
  3. If all samples are classified to different classes.
- ACCEPT
  1. If a majority of the samples are classified to the same class.
  2. If two of the samples are rejected by Ψ_b and one is classified to one of the classes.

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Experimental Results

- The test results
  - Codebook size: about 7 prototype vectors/class
  - Learning algorithms: OLVQ1 and LVQ1
  - 2/3 of footsteps were used for training and 1/3 for testing
  - 13 features was used
    - Normalized between 0 and 1
  - The overall recognition accuracy was 89 % with 18% reject rate (10 randomly chosen test sets)

Recog. rate 3 footsteps	Reject rate 3 footsteps	Recog. rate 1 footstep	Reject rate 1 footstep	0-reject classifier 1 footstep
89.0% (6.7)	18.0% (7.4)	68.9% (5.3)	9.2% (8.6)	66.6% (3.8)

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Conclusions

- Experiments on identifying persons based on their footsteps were reported
- A Method for reliable identification with a reject option was proposed
- Method increases reliability and adaptiviness: detecting spurious patterns and possible unknown persons
- Future plans
  - Developing methods for reconstruction of partial data from multiple sensors
  - Statistical model-based method for footstep segmentation
  - Automatic feature selection
  - Adaptive real-time learning and recognition application for tracking and identification
  - Detecting mobile robot movements from the floor to co-operate with occupants

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