SUPERVISED LEARNING APPROACH FOR RADAR-BASED FALL DETECTION

By:
Hamidreza Sadreazami, Miodrag Bolic and Sreeraman Rajan
MOTIVATION

- Uncontrolled, unintentional and sudden change of posture
- Leading cause of injury and accidental death for seniors

- Wearable devices
- Video cameras
- Smart-phone sensors
WHY CONTACTLESS MONITORING USING RADAR?

• Unlike wearable (contact) devices:
  – No need to wear a device
  – Multiple subjects can be monitored by one device
  – Does not interfere with daily activities
  – Is not sensitive to skin protection products or medication

• Unlike Cameras:
  – Does not invade privacy
  – Performance, generally not affected by environment (light, etc)
  – “Field of view” is large (occlusion is not an issue with certain types of radars).
RADAR - APPLICATIONS

• **Through-the-wall radar**
  - Police, firefighters
  - Finding people under the rubble

• **Detection of posture and activities of people**

• **Detection of stop breathing events**
  - Suicide events
  - Independent living
Goals:

- Fall detection
- Fall prevention
- Vital sign monitoring
- Estimating level of activities during the day
### DATA COLLECTION

- **UWB transceiver** → 5.9-10.3 GHz
- **High spatial resolution**
- **Room measuring** 12.6x4.1 m²
- **Radar Scattering matrix**
  - $m \times n \rightarrow$ slow-time/fast-time
- **15 seconds segments**
- **Sampling rate:** 200 Hz
- **Range bins:** 5.35 cm
- **3000x189**

### Manual labeling
- **Supervised learning**
Fig. 1. Postures in room environment; before and after a fall incident (a) Standing and (b) Lying down.

<table>
<thead>
<tr>
<th>Class</th>
<th>Description</th>
<th># of Exp.</th>
<th># of Exp. after augmentation (×10)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fall</td>
<td>Stand along the radar line of sight and fall down</td>
<td>61</td>
<td>610</td>
</tr>
<tr>
<td>Fall</td>
<td>Walk toward the radar line of sight and fall down</td>
<td>59</td>
<td>590</td>
</tr>
<tr>
<td>Fall</td>
<td>Stand and fall down perpendicularly</td>
<td>67</td>
<td>670</td>
</tr>
<tr>
<td>Non-fall</td>
<td>Lie down and stand up</td>
<td>85</td>
<td>850</td>
</tr>
<tr>
<td>Non-fall</td>
<td>Lie down and stand up perpendicularly</td>
<td>64</td>
<td>640</td>
</tr>
</tbody>
</table>
PROPOSED METHODS

• **Time series analysis of the radar return signals**
  
  1D CNN, LSTM, ResNet, DTW, KNN, ...

• **Binary image representation of TF signals**
  
  2D CNN, KNN, SVM, DT, ...
  
  CS, autoencoders

• **Color image representation of TF signals**
  
  2D CNN, KNN, SVM, DT, ...
  
  CapsNet
\[ x_i = \sum_j \frac{x_{i,j}}{\max_j(|x_{i,j}|)} \]

Falling down
TIME-SERIES ANALYSIS

Standing up
TIME-FREQUENCY ANALYSIS

Falling down

- Time-Frequency
- Spectrogram
TIME-FREQUENCY ANALYSIS

Normalized Amplitude

Standing up
**TRANSFER LEARNING**

- Small dataset \(\rightarrow\) Transfer Learning

**VGG-16**

5 convolutional blocks \(\rightarrow\) Freeze the first 4 blocks and retrain the last one.

3x3 Convolutional filters

2x2 Pooling layer
TRANSFER LEARNING

Radar Spectrograms → Conv. block 1-4 → Conv. block 5

VGG16

Conv. block 5

Conv. 3×3 → Conv. 3×3 → Conv. 3×3 → MP 2×2 → GAP

Output layer with softmax

Fall/Non-fall
RESULTS

Table I. Accuracy, precision and sensitivity values (%) obtained using the proposed transfer learning-based method, when fine-tuning the VGG16 model with or without convolutional layers in a 3-fold cross-validation sense.

<table>
<thead>
<tr>
<th>Method</th>
<th>Accuracy</th>
<th>Precision</th>
<th>Sensitivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 Conv+MP+GAP+Output</td>
<td>95.64</td>
<td>96.12</td>
<td>96.73</td>
</tr>
<tr>
<td>1 Conv+MP+GAP+Output</td>
<td>95.64</td>
<td>96.12</td>
<td>96.73</td>
</tr>
<tr>
<td>MP+GAP+Output</td>
<td>89.80</td>
<td>90.72</td>
<td>92.37</td>
</tr>
<tr>
<td>GAP+Output</td>
<td>89.32</td>
<td>90.89</td>
<td>91.66</td>
</tr>
</tbody>
</table>
RESULTS

Table II. Accuracy, precision and sensitivity values (%) obtained using the proposed transfer learning based method and those provided by LSVM, GSVM and KNN in a 3-fold cross-validation.

<table>
<thead>
<tr>
<th>Method</th>
<th>Accuracy</th>
<th>Precision</th>
<th>Sensitivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>LSVM</td>
<td>80.01</td>
<td>82.64</td>
<td>83.34</td>
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<tr>
<td>GSVM</td>
<td>79.13</td>
<td>85.12</td>
<td>80.46</td>
</tr>
<tr>
<td>KNN</td>
<td>78.64</td>
<td>82.64</td>
<td>81.30</td>
</tr>
<tr>
<td>Proposed</td>
<td>95.64</td>
<td>96.12</td>
<td>96.73</td>
</tr>
</tbody>
</table>
CHALLENGES

• Subjects may fall in different directions relative the radar.
  In perpendicular to the radar → more false negatives

Multiple radar sensors
Integrating range info

• Data Augmentation
  Rotation, width shifting, height shifting, horizontal flipping, shearing, zooming
  • Fall/non-fall activities at different distances to the radar
  • Sitting down abruptly and bending over
FUTURE DIRECTIONS IN THE FIELD

• **Problems**
  - Detection in an uncontrolled environment
  - Multiple people identification and tracking
  - Supervised algorithms trained only for a number of specific cases

• **Potential directions**
  - Improvements of the sensors or new sensors
  - Sensor fusion at the massive scale
  - Inferring actions and conditions using unsupervised learning techniques
INFO

My Webpage:
http://sadreazami.research.mcgill.ca/

Group Webpage:
http://meddev.eecs.uottawa.ca/radar.html

Group Github:
https://github.com/Health-Devices-Research-Group

Hamidreza Sadreazami
Postdoctoral Fellow- McGill Uni.
hsadreaz@uottawa.ca
@5145570594