SUPERVISED LEARNING APPROACH FOR RADAR-BASED FALL DETECTION

uOttawa

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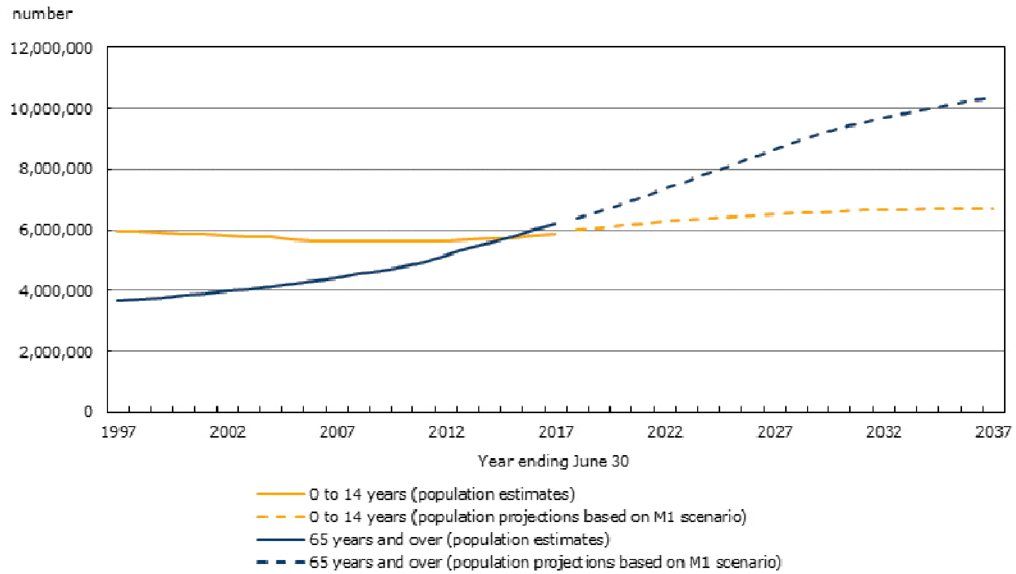
MOTIVATION

- Uncontrolled, unintentional and sudden change of posture
- Leading cause of injury

  and accidental death for seniors

Chart 2.1
Population aged 0 to 14 years and 65 years and over, 1997 to 2037, Canada



Note: From 1997 to 2017, population estimates. From 2018 to 2037, *Population Projections for Canada (2013 to 2063), Provinces and Territories, (2013 to 2038), Catalogue no. 91-520-X.*
Source: Statistics Canada, Demography Division.

- 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

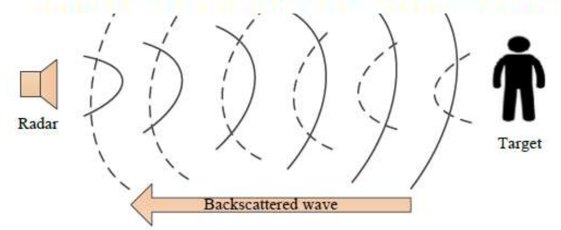
RADAR

Goals:

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

(a)

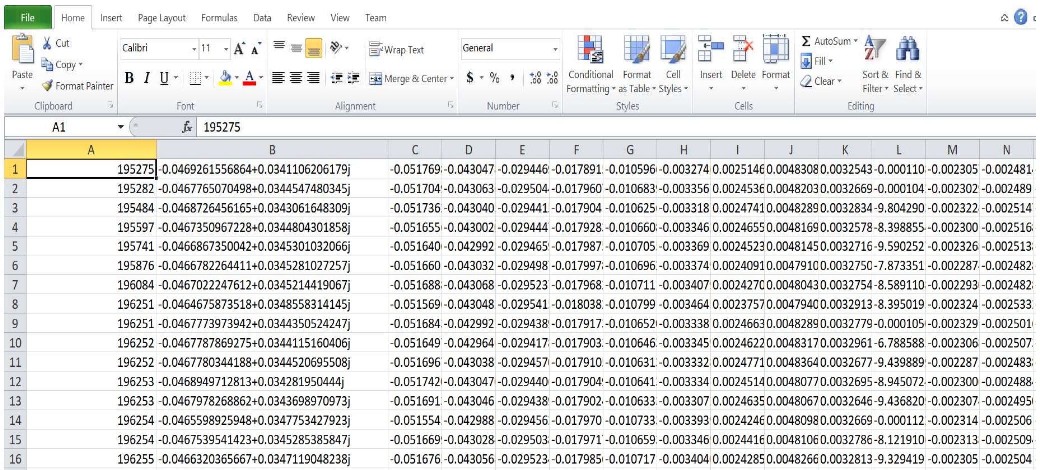
Novelda Xethru X4M03 radar



(b)

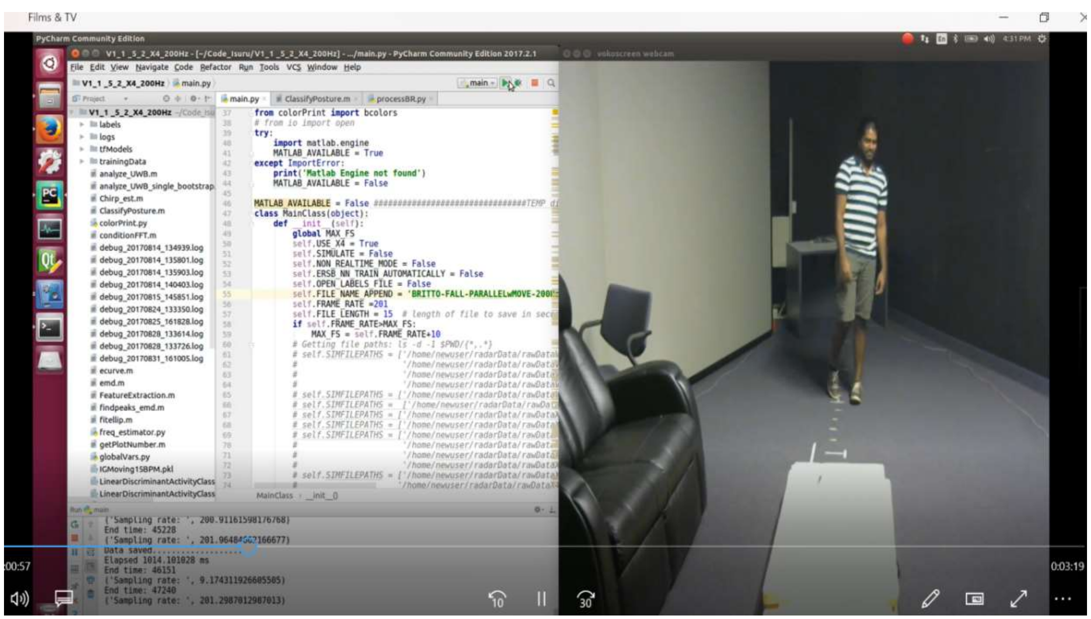
Radar signal transmission

DATA COLLECTION



	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	195275	-0.0469261556864+0.0341106206179j	-0.051769	-0.043047	-0.029446	-0.017891	-0.010596	-0.003274	0.0025146	0.0048308	0.0032543	-0.000110	-0.002305	-0.002481
2	195282	-0.0467765070498+0.0344547480345j	-0.051704	-0.043063	-0.029504	-0.017960	-0.010683	-0.003356	0.0024536	0.0048203	0.0032669	-0.000104	-0.002302	-0.002489
3	195484	-0.0468726456165+0.0343061648309j	-0.051736	-0.043040	-0.029441	-0.017904	-0.010625	-0.003318	0.0024741	0.0048289	0.0032834	-9.804290	-0.002322	-0.002514
4	195597	-0.0467350967228+0.0344804301858j	-0.051655	-0.043002	-0.029444	-0.017928	-0.010660	-0.003346	0.0024655	0.0048169	0.0032578	-8.398855	-0.002300	-0.002516
5	195741	-0.0466867350042+0.0345301032066j	-0.051640	-0.042992	-0.029465	-0.017987	-0.010705	-0.003369	0.0024523	0.0048145	0.0032716	-9.590252	-0.002326	-0.002513
6	195876	-0.0466782264411+0.0345281027257j	-0.051660	-0.043032	-0.029498	-0.017997	-0.010696	-0.003374	0.0024091	0.0047910	0.0032750	-7.873351	-0.002287	-0.002482
7	196084	-0.0467022247612+0.0345214419067j	-0.051688	-0.043068	-0.029523	-0.017968	-0.010711	-0.003407	0.0024270	0.0048043	0.0032754	-8.589110	-0.002293	-0.002482
8	196251	-0.0464675873518+0.0348558314145j	-0.051569	-0.043048	-0.029541	-0.018038	-0.010799	-0.003464	0.0023757	0.0047940	0.0032913	-8.395019	-0.002324	-0.002533
9	196251	-0.0467773973942+0.0344350524247j	-0.051684	-0.042992	-0.029438	-0.017917	-0.010652	-0.003338	0.0024663	0.0048289	0.0032779	-0.000105	-0.002329	-0.002501
10	196252	-0.0467787869275+0.0344115160406j	-0.051649	-0.042964	-0.029417	-0.017903	-0.010646	-0.003345	0.0024622	0.0048317	0.0032961	-6.788588	-0.002306	-0.002507
11	196252	-0.0467780344188+0.0344520695508j	-0.051696	-0.043038	-0.029457	-0.017910	-0.010631	-0.003332	0.0024771	0.0048364	0.0032677	-9.439889	-0.002287	-0.002483
12	196253	-0.046894971281 3+0.034281950444j	-0.051742	-0.043047	-0.029440	-0.017904	-0.010641	-0.003334	0.0024514	0.0048077	0.0032695	-8.945072	-0.002300	-0.002488
13	196253	-0.0467978268862+0.0343698970973j	-0.051691	-0.043046	-0.029438	-0.017902	-0.010633	-0.003307	0.0024635	0.0048067	0.0032646	-9.436820	-0.002307	-0.002495
14	196254	-0.0465598925948+0.0347753427923j	-0.051554	-0.042988	-0.029456	-0.017970	-0.010733	-0.003393	0.0024246	0.0048098	0.0032669	-0.000112	-0.002314	-0.002506
15	196254	-0.0467539541423+0.0345285385847j	-0.051669	-0.043028	-0.029503	-0.017971	-0.010659	-0.003346	0.0024416	0.0048106	0.0032786	-8.121910	-0.002313	-0.002509
16	196255	-0.0466320365667+0.0347119048238j	-0.051676	-0.043056	-0.029523	-0.017985	-0.010717	-0.003404	0.0024285	0.0048266	0.0032813	-9.329419	-0.002305	-0.002504

- UWB transceiver → 5.9-10.3 GHz
- High spatial resolution
- Room measuring 12.6x4.1 m^2
- Radar Scattering matrix
  mxn → slow-time/fast-time
- 15 seconds segments
- Sampling rate: 200 Hz
- Range bins: 5.35 cm
- 3000x189



- Manual labeling
- Supervised learning

DATASET

(a) (b)

Fig. 1. Postures in room environment; before and after a fall incident (a) Standing and (b) Lying down.

TABLE I

TYPES AND NUMBER OF ACTIVITIES PERFORMED IN OUR EXPERIMENTS BY 10 DIFFERENT SUBJECTS IN THE TWO DIFFERENT ROOM ENVIRONMENTS.

Class	Description	# of Exp.	# of Exp. after augmentation ($\times 10$)
Fall	Stand along the radar line of sight and fall down	61	610
Fall	Walk toward the radar line of sight and fall down	59	590
Fall	Stand and fall down perpendicularly	67	670
Non-fall	Lie down and stand up	85	850
Non-fall	Lie down and stand up perpendicularly	64	640

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**

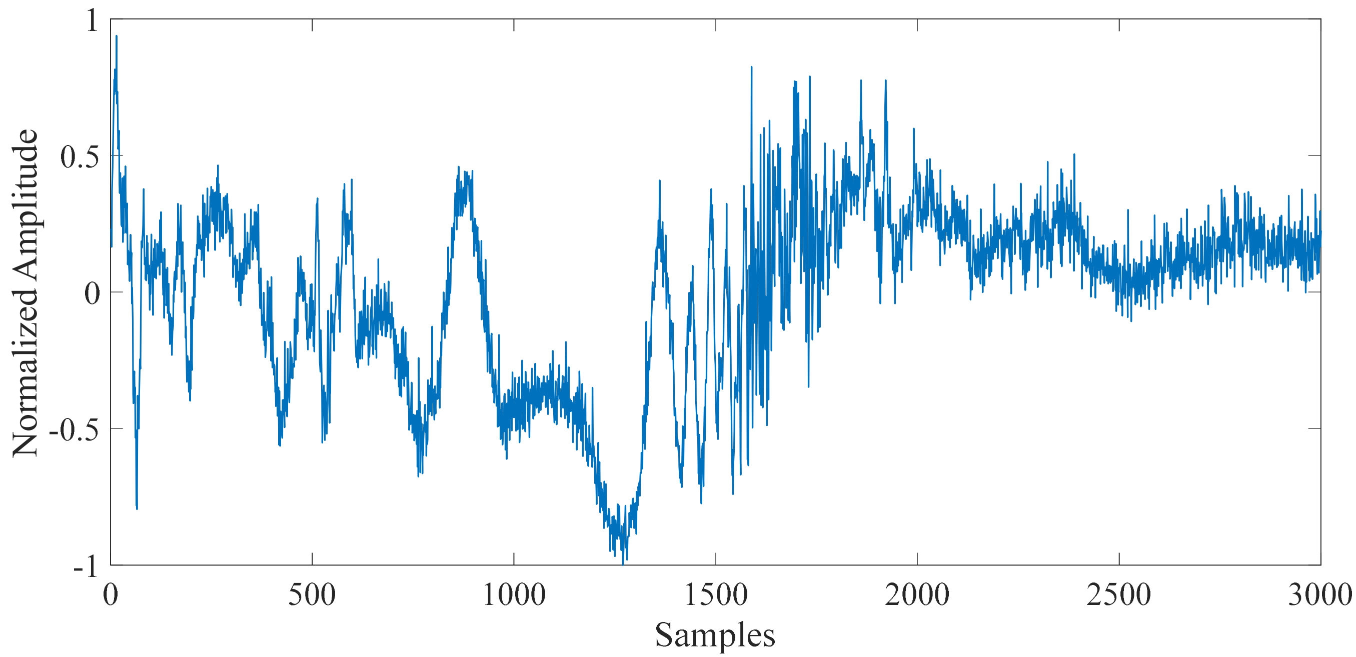
  2D CNN, KNN, SVM, DT, …

  CapsNet

TIME-SERIES ANALYSIS

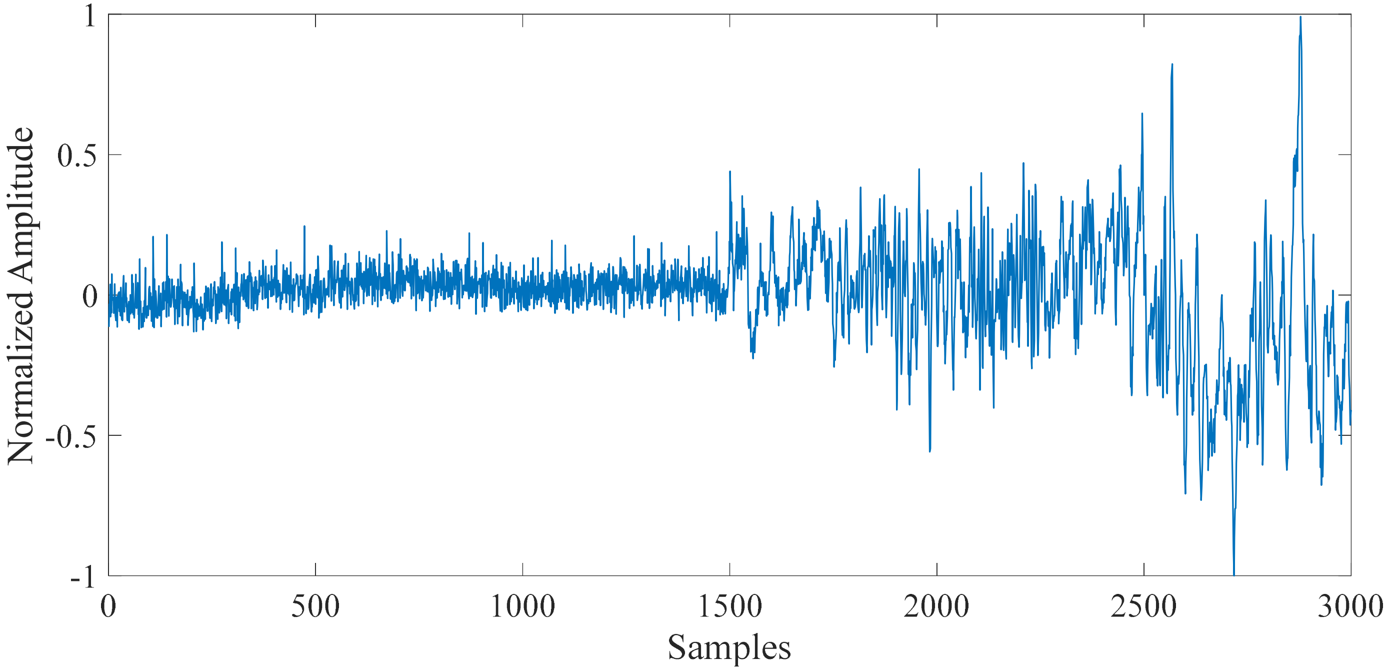
$$\mathbf{x}_i = \sum_j \frac{x_{i,j}}{\underbrace{\max}_j(|x_{i,j}|)},$$

Falling down

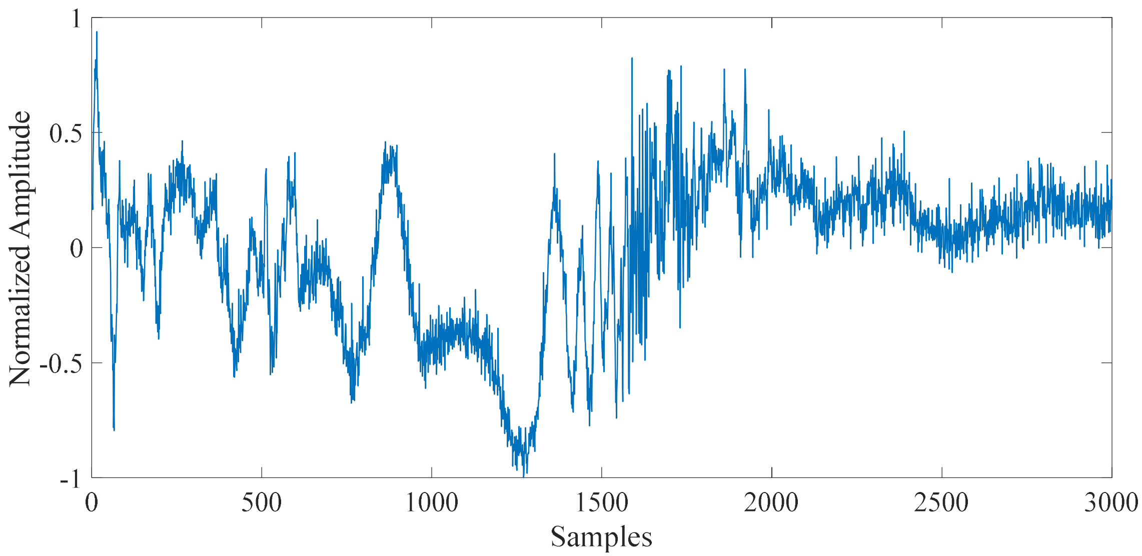


TIME-SERIES ANALYSIS

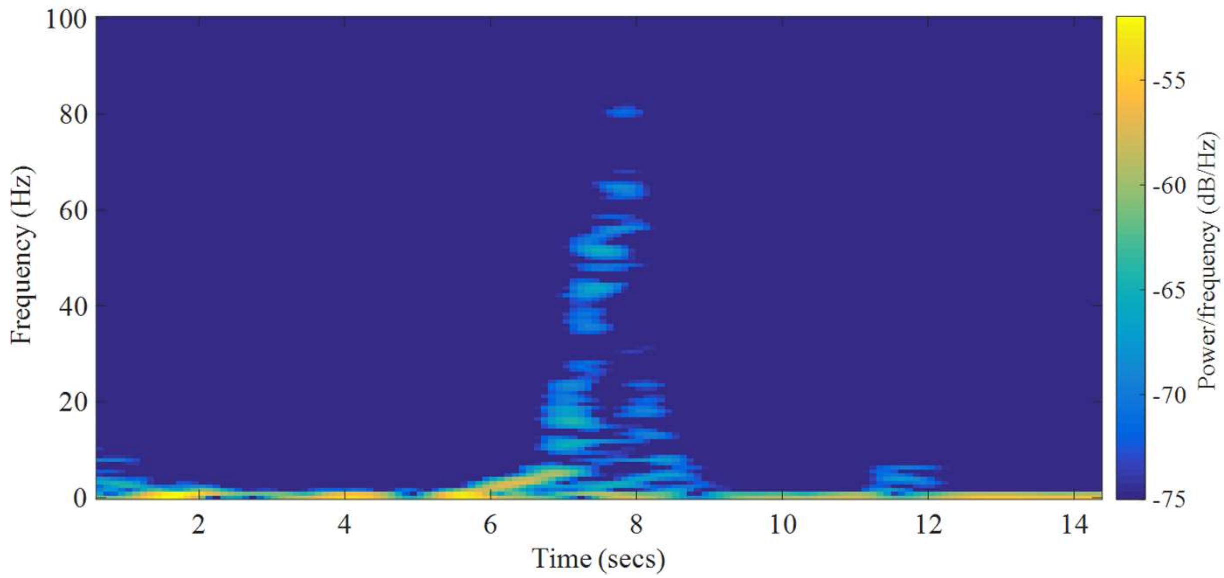
Standing up



TIME-FREQUENCY ANALYSIS

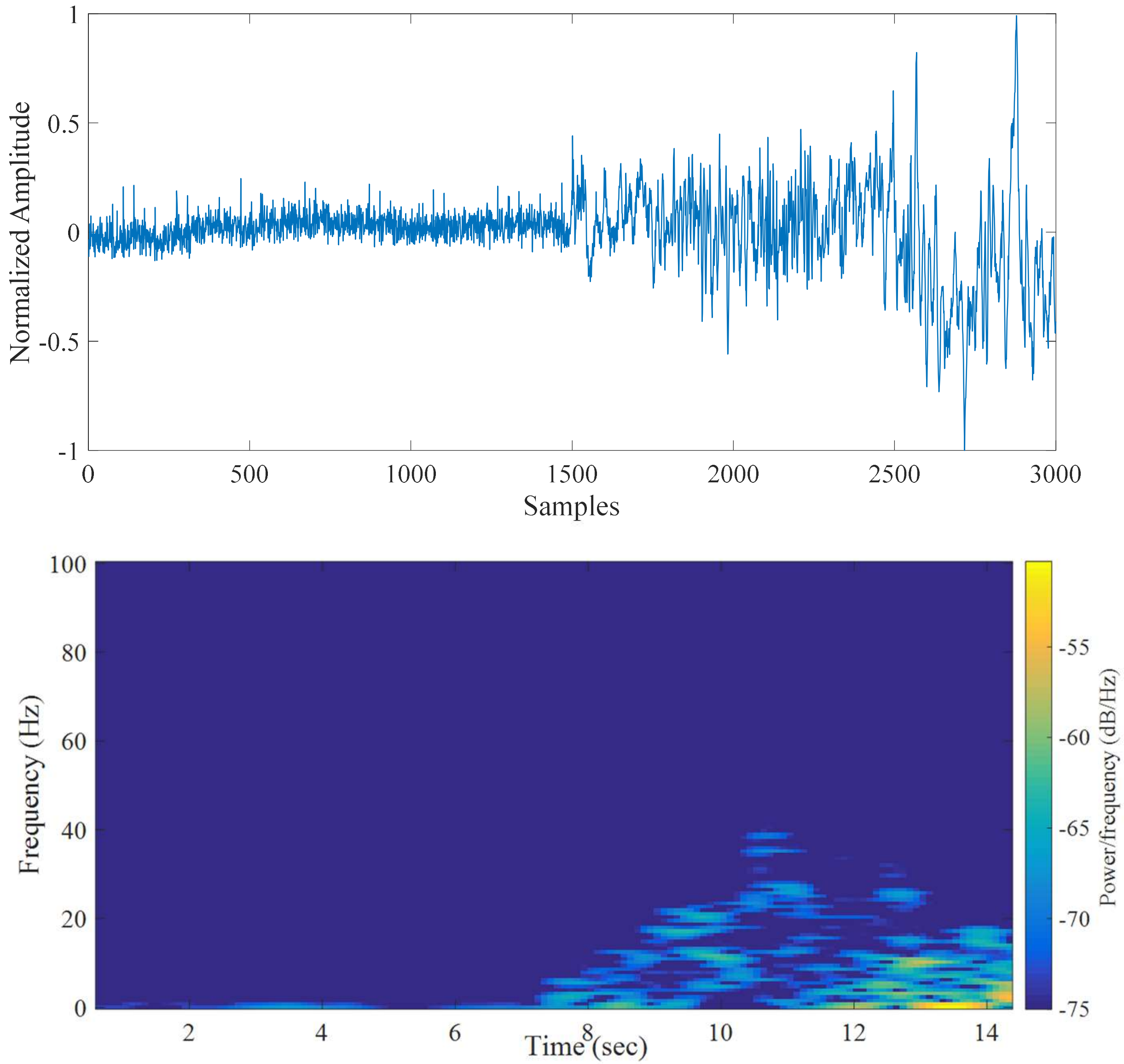


Falling down



- Time-Frequency
- Spectrogram

TIME-FREQUENCY ANALYSIS



Standing up

TRANSFER LEARNING

- Small dataset → Transfer Learning

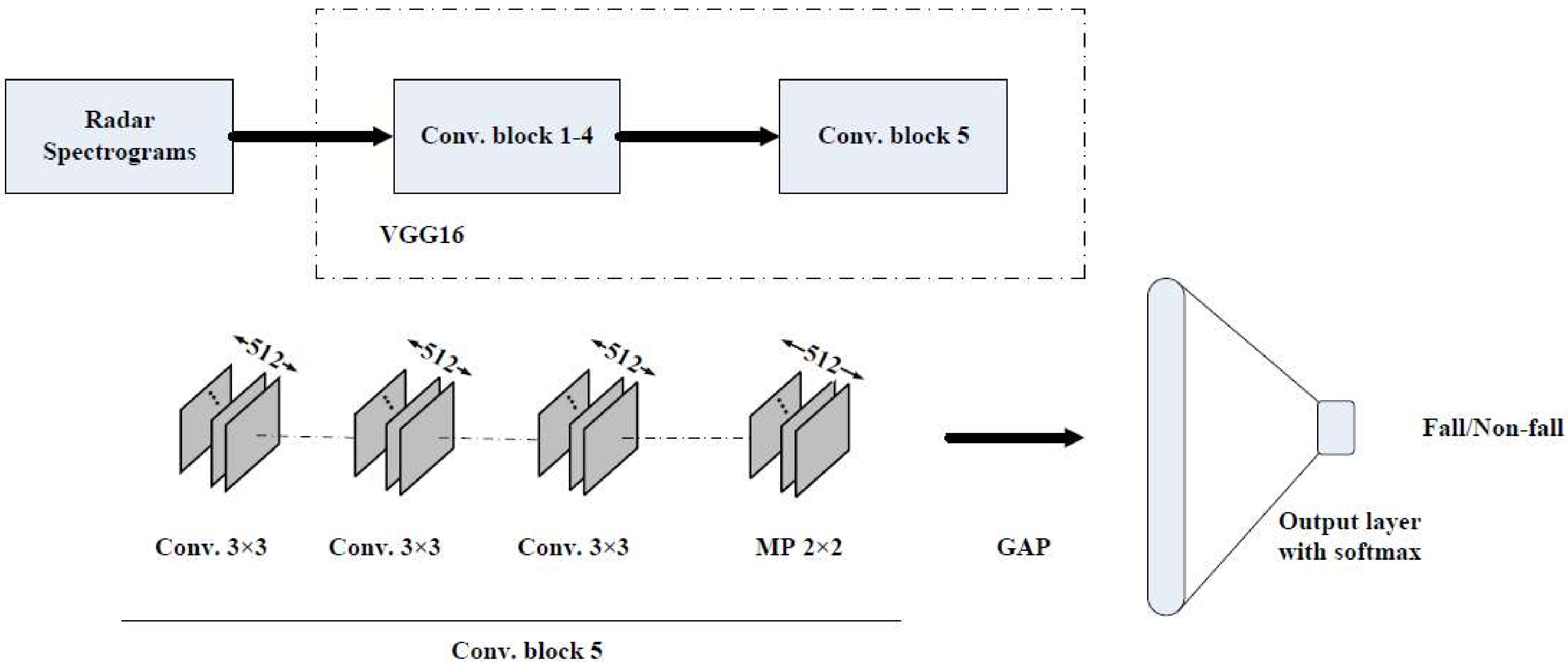
VGG-16

5 convolutional blocks → Freeze the first 4 blocks and retrain the last one.

3x3 Convolutional filters

2x2 Pooling layer

TRANSFER LEARNING



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.

	Metrics		
Method	Accuracy	Precision	Sensitivity
2 Conv+MP+GAP+Output	95.64	96.12	96.73
1 Conv+MP+GAP+Output	95.64	96.12	96.73
MP+GAP+Output	89.80	90.72	92.37
GAP+Output	89.32	90.89	91.66

RESULTS

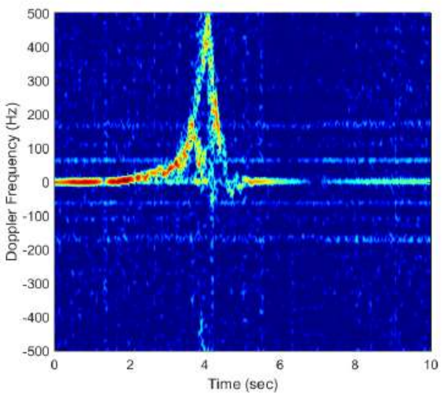
Table II. Accuracy, precision and sensitivity values (%) obtained using the proposed transfer learning based method and those provided by LSVM, GSVM and KNN in a 3-fold cross-validation.

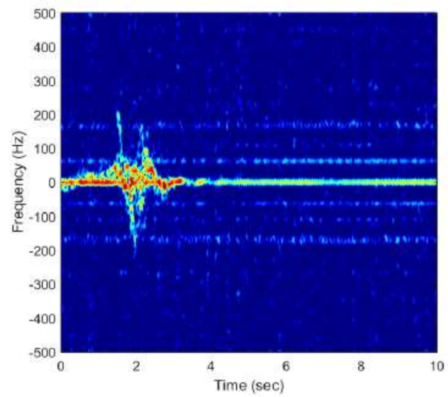
	Metrics		
Method	Accuracy	Precision	Sensitivity
LSVM	80.01	82.64	83.34
GSVM	79.13	85.12	80.46
KNN	78.64	82.64	81.30
Proposed	**95.64**	**96.12**	**96.73**

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

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