Master's degree ICT Internet Multimedia Engineering

MACHINE LEARNING FOR HUMAN DATA – FINAL EXAMINATION

Instructor

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Lab. classes

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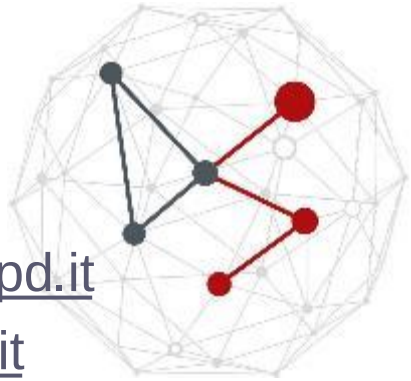

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General guidelines

The final exam is project-based

- This does not mean that you can avoid understanding the theory…see the next slides

1. Pick a project among the 11 options that we provide to you: each consists of a challenge and an associated dataset
2. Design one/more original solution(s) to the problem based on neural networks, implement it/them in TensorFlow and evaluate and compare the performance
3. Prepare a report and a presentation describing your work

- You can work in a group with another student
  - max 2 people per group
  - you are free to arrange the groups
  - both members have to contribute to the work

Exam dates and submission deadlines

- Exam: January 28-29, 2025
  - report+code submission deadline: Jan. 25, 2025
- Exam: February 18-19, 2025
  - report+code submission deadline: Feb. 15, 2025
- Exam: June 18-19, 2025
  - report+code submission deadline: June 15, 2025
- Exam: July 2-3, 2025
  - report+code submission deadline: June 29, 2025
- Exam: September 18-19, 2025
  - report+code submission deadline: Setp. 15, 2025

IMPORTANT NOTES on next page!

Exam dates: important notes

- The exam will be held in presence
  - online exams are no longer allowed by UNIPD

- Depending on the number of students we may need to split you into groups that will take the exam on different days
  - the exam dates in the previous slide indicate the first days of the session
  - please, be prepared to be scheduled for a different day than the one indicated (try to be available for the day of the exam and the following ones; in case you have unmovable appointments, inform us **as soon as you enroll**)
  - we will send you the schedule some days before the exam when the UNIWEB enrollment will close

For the final examination you must

GROUP SELF-SELECTION

Group and project self-selection

1. Fill out the group selection form in Moodle indicating the students (1 or 2) in your group (we will send the instructions through the Moodle's news channel) → remember to do that!

ASSIGNMENT

Project report and code upload - January 28-29, 2025

2. Upload in Moodle (following the instructions about naming etc.)

FILE

Project report - Latex template

   A. a report (use the LaTex template available on Moodle)
   B. the code of the implementation in **TensorFlow**

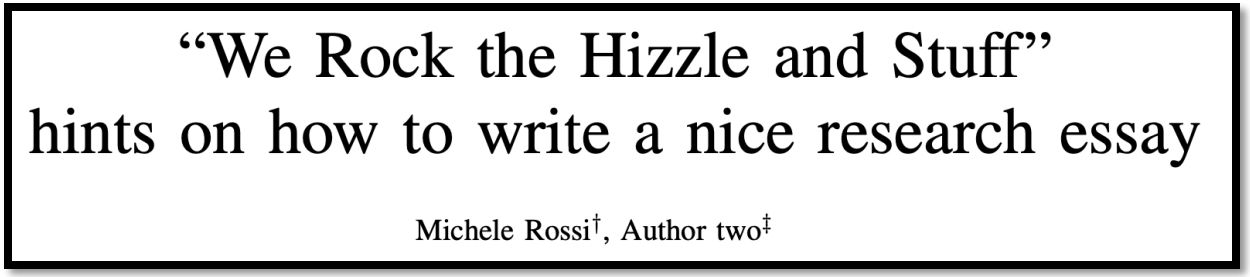
3. Prepare a presentation through slides (20 minutes strict, possibly including a demo) for the day of the exam

The report

1. Should be done in LaTex following the template available on Moodle
2. Should be written in a clear and organized manner
3. Should include graphical presentations of your approaches
4. Should clearly show and discuss the results

FILE

Project report - Latex template



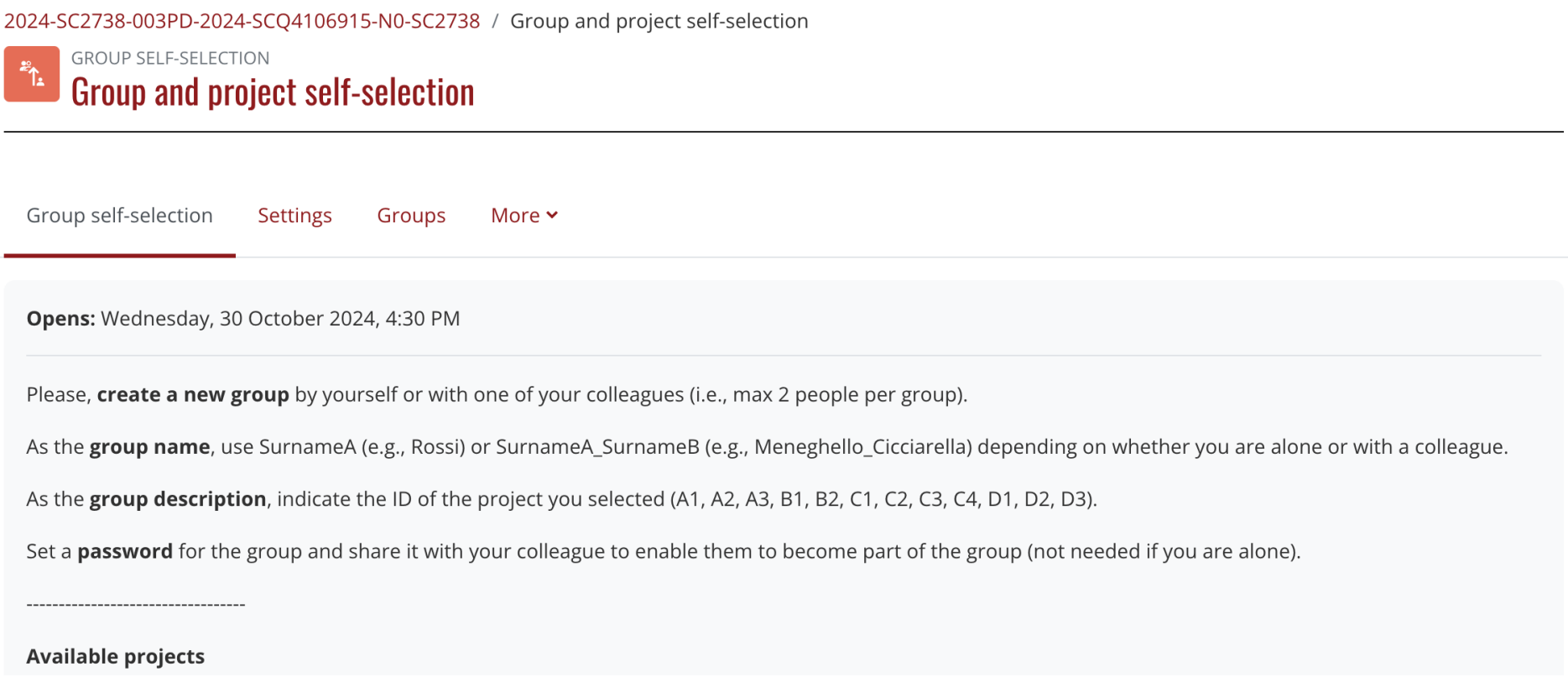
"We Rock the Hizzle and Stuff"
hints on how to write a nice research essay

Michele Rossi†, Author two‡

Group self-selection in Moodle

Deadline: when you enroll in UNIWEB for the exam

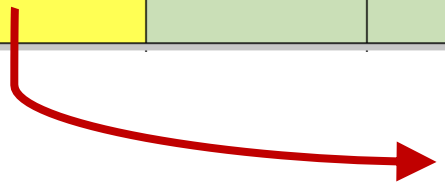
You can fill it out also before (recommended)



Evaluation

- The evaluation will consider different aspects
  - about the report, the presentation and the project itself

project					written report			oral	
originality (10)	preprocessing (10)	learning architecture (15)	comparison / performance analysis (10)	live demo (10)	clarity of exposition (10)	completeness of results (accuracy, complexity, time) (10)	technical soundness (15)	duration (10)	clarity (10)



Show how the approach works on some examples (using pre-trained networks) or a walkthrough

- Your grade will be computed by:
  1. Summig the points (max 110)
  2. Multiplying the sum by 0.424242
  3. Subtracting 11.69
  4. Limiting the score in [0, 32]

see the details in the LaTex template for the final report (on Moodle)

Guidelines

- Prepare the project and the report considering the grid we use for the evaluation (see previous slide)
  - pay attention to the pre-processing phase (normalize the data)
  - create original neural network architectures
  - compare the performance of different approaches (use the correct metrics...check about data balancing)
  - evaluate the performance of the algorithms in terms of running time and complexity (memory occupation)

Guidelines

- Be creative!
  - We provided you with some ideas for possible project developments, but original works are always welcome!
  - You can use the neural network architectures seen during the labs and/or experiment with new approaches!
  - We provide you with some references but try to explore a bit other contributions in the literature that may be helpful (search for them in https://scholar.google.it/)
  - Pre-processing techniques may be useful
  - Implement your own neural network architecture…DO NOT use pre-trained models from Keras: the objective of the project is that you put into practice the things you learned during the theoretical lessons, not to improve your skills about reusing networks/code developed by others :)

Guidelines

- The use of TensorFlow is mandatory
  - Pytorch is only allowed for spiking neural networks through snntorch
- The use of pretrained networks is not allowed
  - You can use them for comparison but cannot be the main architectures
- During the exam we will ask you the reasoning behind using the specific architectures (e.g., CNN/RNN/attention…)
  - **Do not use the NN functions as black boxes**: you need to understand why you are using the specific architectures
  - **REMEMBER**: Python is not intelligent, it takes something as input and provides an output, it only checks the shape of the data → pay attention and use your theoretical knowledge

Common mistakes to avoid

- Data not correctly normalized
  - This is an important step for ML algorithms to not have biases in the algorithm
- Preprocessing not considered
  - In addition to ML you may need to apply some signal processing algorithms to clean the data before NN
- Train/validation/test sets not correctly split
  - The three sets do not have to overlap: no data from training should be used during validation or test
- Validation performed on a small number of samples that is not statistically significant
  - e.g., evaluation performed on 1 or 2 samples…
- Complexity of the algorithms in terms of time and memory not analyzed
- Use wrong input data
  - e.g., for IMU datasets, obtain the activity prediction by using single IMU measurements and not a sequence of measurements

Proposed Projects

PART A – ON BODY AND ENVIRONMENTAL SENSORS

1) A1: Activity recognition with four accelerometers
2) A2: Pathological gait recognition
3) A3: Motor imagery classification from EEG for brain–computer interface

PART B – AUDIO SIGNALS

1) B1: Speech command recognition (keyword spotting)
2) B2: Environmental sound classification

PART C – IMAGES

1) C1: Sleep posture monitoring
2) C2: Bone age prediction from hand radiographs
3) C3: Lung disease prediction from X-ray images
4) C4: Blood cell type prediction

PART D – RADIO SIGNALS

1) D1: Activity recognition through Wi-Fi devices
2) D2: Gesture recognition through radars

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PART A: ON BODY AND ENVIRONMENTAL SENSORS

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PART D – RADIO SIGNALS

1) D1: Activity recognition through Wi-Fi devices
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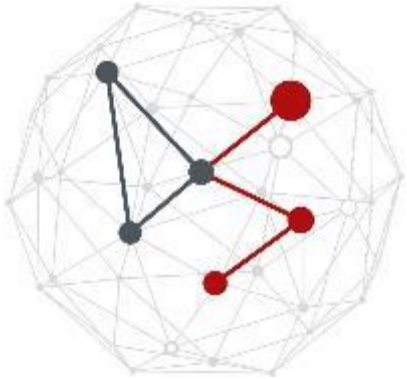
PROJECT A1



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Project A1 “Activity recognition with four accelerometers”

Reference papers

[Fadel19] Fadel, W. F., Urbanek, J. K., Albertson, S. R., Li, X., Chomistek, A. K., & Harezlak, J., Differentiating Between Walking and Stair Climbing Using Raw Accelerometry Data, in Statistics in Biosciences, 11(2), 334–354, 2019.

[Karas19] Karas, M., Bai, J., Strączkiewicz, M., Harezlak, J., Glynn, N. W., Harris, T., … Urbanek, J. K., Accelerometry Data in Health Research: Challenges and Opportunities. Review and Examples, in Statistics in Biosciences, 11, 210–23, 2019.

Dataset (760.8 MB uncompressed)

https://physionet.org/content/accelerometry-walk-climb-drive/1.0.0/

Why is activity recognition important?

- Navigation systems
  - adapt to user movement
  - e.g., predict direction and only use that portion of the map(s)
  - put the system into power saving mode when there is no mobility
- First responders
  - security personnel, firefighters
  - e.g., who has to be assisted first
- Assisted living
  - react to reduced activity levels
  - unusual mobility patterns
  - user motion-aware services and/or environments
- Rehabilitation
  - measure recovery of motor functions
  - measure effectiveness of rehabilitation
- In most of these cases the use of cameras is not possible
- The system has to be unobtrusive, lightweight, portable, … → use IMU or radio waves

Dataset description

- Four 3-axial ActiGraph GT3X+ wearable accelerometers at
  1. left ankle
  2. right ankle
  3. left hip
  4. left wrist
- Dataset: collected from 13 males & 19 females aged between 23 and 52
- Six activities considered
  - 1=walking
  - 2=descending stairs
  - 3=ascending stairs
  - 4=driving
  - 77=clapping
  - 99=non-study activity

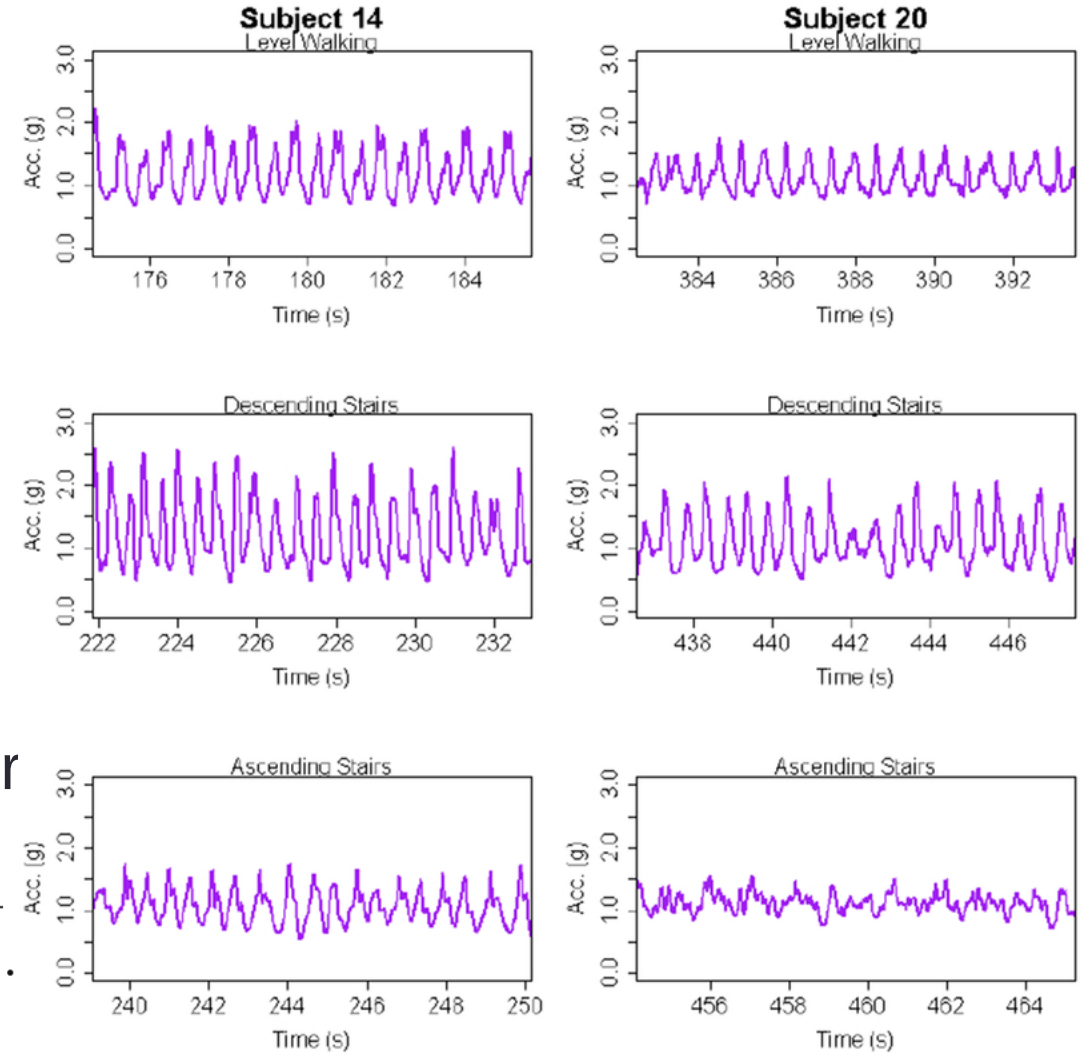
Dataset description

- Dataset format → Text file: 14 variables
  - activity: Type of activity
  - time_s: Time from device initiation (seconds [s])
  - lw_x: Left wrist x-axis measurement (gravitation acceleration [g])
  - lw_y: Left wrist y-axis measurement (gravitation acceleration [g])
  - lw_z: Left wrist z-axis measurement (gravitation acceleration [g])
  - lh_x: Left hip x-axis measurement (gravitation acceleration [g])
  - lh_y: Left hip y-axis measurement (gravitation acceleration [g])
  - lh_z: Left hip z-axis measurement (gravitation acceleration [g])
  - la_x: Left ankle x-axis measurement (gravitation acceleration [g])
  - la_y: Left ankle y-axis measurement (gravitation acceleration [g])
  - la_z: Left ankle z-axis measurement (gravitation acceleration [g])
  - ra_x: Right ankle x-axis measurement (gravitation acceleration [g])
  - ra_y: Right ankle y-axis measurement (gravitation acceleration [g])
  - ra_z: Right ankle z-axis measurement (gravitation acceleration [g])

Dataset description

- No information is provided to convert the data into the global frame
- In [Fadel19] authors consider the vector magnitude to remove the effects of the sensor orientation

$$vm(t) = \sqrt{x(t)^2 + y(t)^2 + z(t)^2}.$$



Possible project developments

- Walking VS stairs climbing
  - 3-class classification problem
  - consider the first three activities as in [Fadel19]
- Features
  - use the magnitude or try to use the information on the 3 axes
  - use the features defined in [Fadel19], or
  - compute features with FFT/DCT in an audio-like fashion, or
  - use raw signals with automatic feature extraction
- Classification architecture
  - CNN or RNN…SNN
- REMEMBER: this is about sequential data…you cannot perform the classification by considering a single sample (a common mistake)

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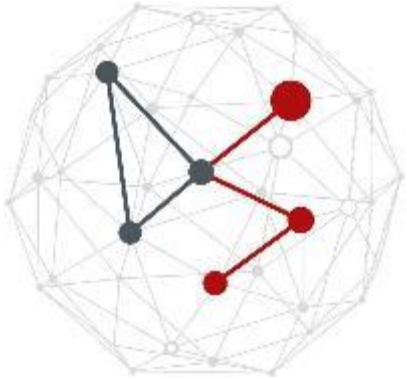
PROJECT A2



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Project A2 “Pathological gait recognition”

Reference papers

[Jun20_1] K. Jun, Y. Lee, S. Lee, D.-W. Lee, and M. S. Kim, Pathological Gait Classification Using Kinect v2 and Gated Recurrent Neural Networks, IEEE Access, vol. 8, pp. 139881-139891, 2020.

[Jun20_2] K. Jun, D. W. Lee, K. Lee, S. Lee, and M. S. Kim, Feature Extraction Using an RNN Autoencoder for Skeleton-based Abnormal Gait Recognition, IEEE Access, vol. 8, pp. 19196-19207, 2020.

[Lee19] D. W. Lee, K. Jun, S. Lee, J. K. Ko, and M. S. Kim, Abnormal gait recognition using 3D joint information of multiple Kinects system and RNN-LSTM, in Proceedings of the 41st Annual International Conference of the IEEE Engineering in Medicine and Biology Society, 2019.

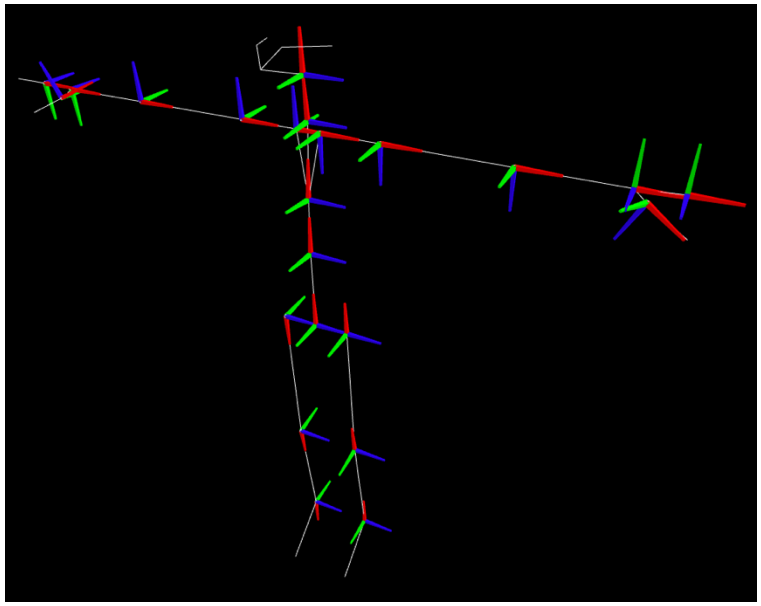
Dataset (111.22 MB uncompressed)

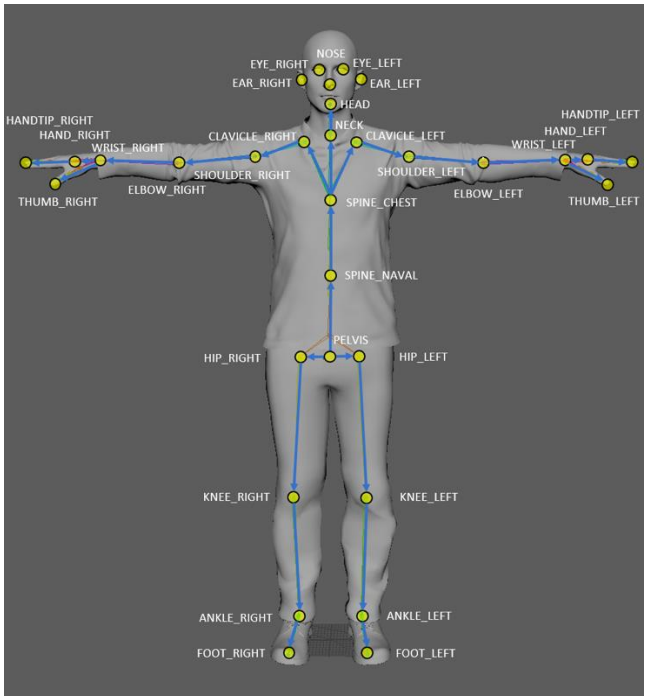
https://drive.google.com/file/d/1BLUXyk_59agThysXwamfVyZahSI-sScI/view?usp=sharing

https://ieee-dataport.org/documents/azure-kinect-3d-skeleton-and-foot-pressure-data-pathological-gaits

Dataset description

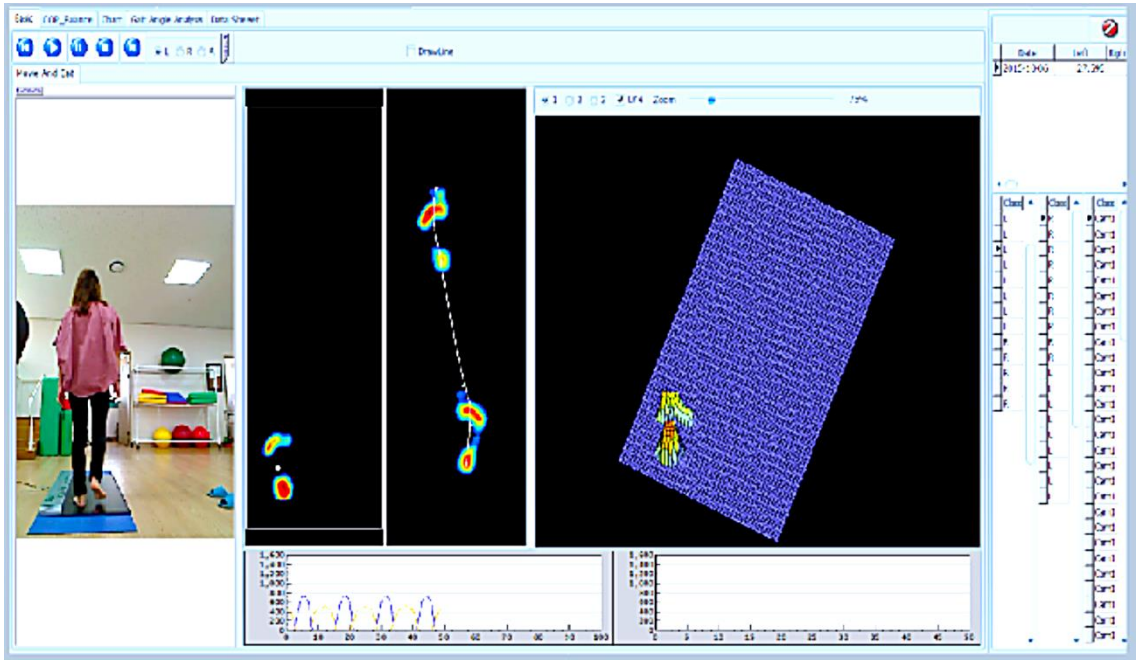
- Sequential skeleton data
  - Azure Kinect (Microsoft Corp. Redmond, WA, USA)
  - https://docs.microsoft.com/en-us/azure/kinect-dk/body-joints





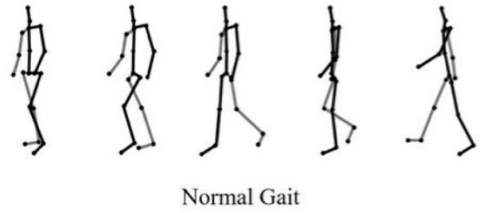
Dataset description

- Average foot pressure data
  - GW1100 (GHIWell, Korea)
  - size = 48 x 128
  - GW1100 is a 1080mm x 480mm sized pressure plate and contains 6,144 high-voltage matrix sensors with maximum pressure 100 N/cm^2

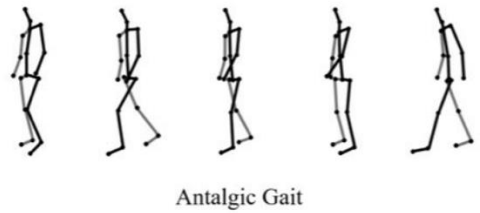


Dataset description

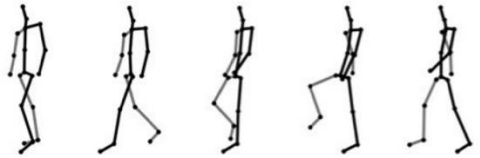
- Simultaneously collected data from the two sensors for normal and five pathological gaits
  1. antalgic
  2. lurching
  3. steppage
  4. stiff-legged
  5. Trendelenburg



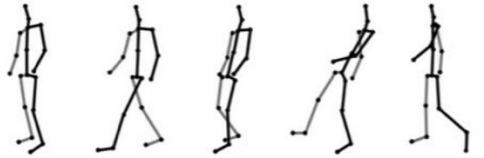
Normal Gait



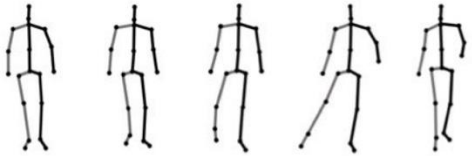
Antalgic Gait



Steppage Gait



Lurching Gait



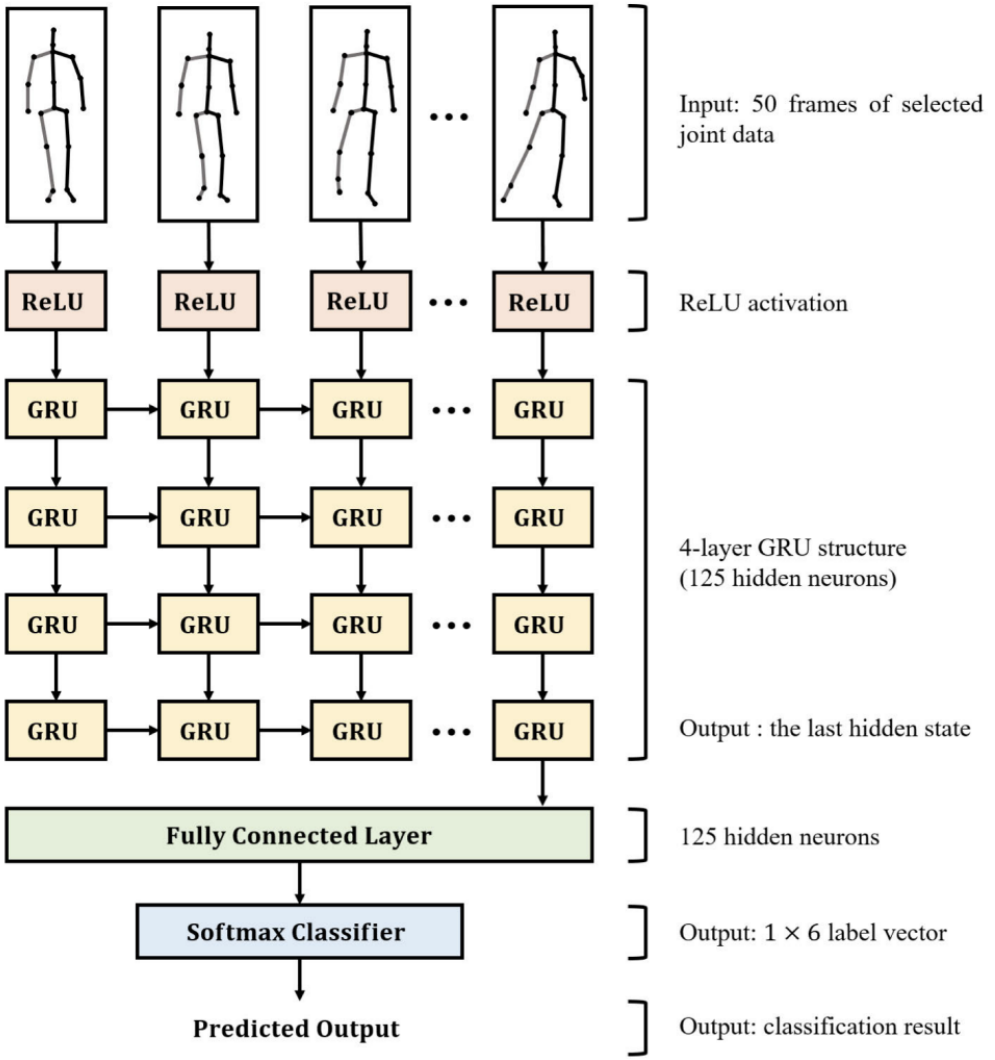
Stiff-legged Gait

Trendelenburg Gait

- 1,440 data instances (12 people x 6 gait types x 20 walkings)

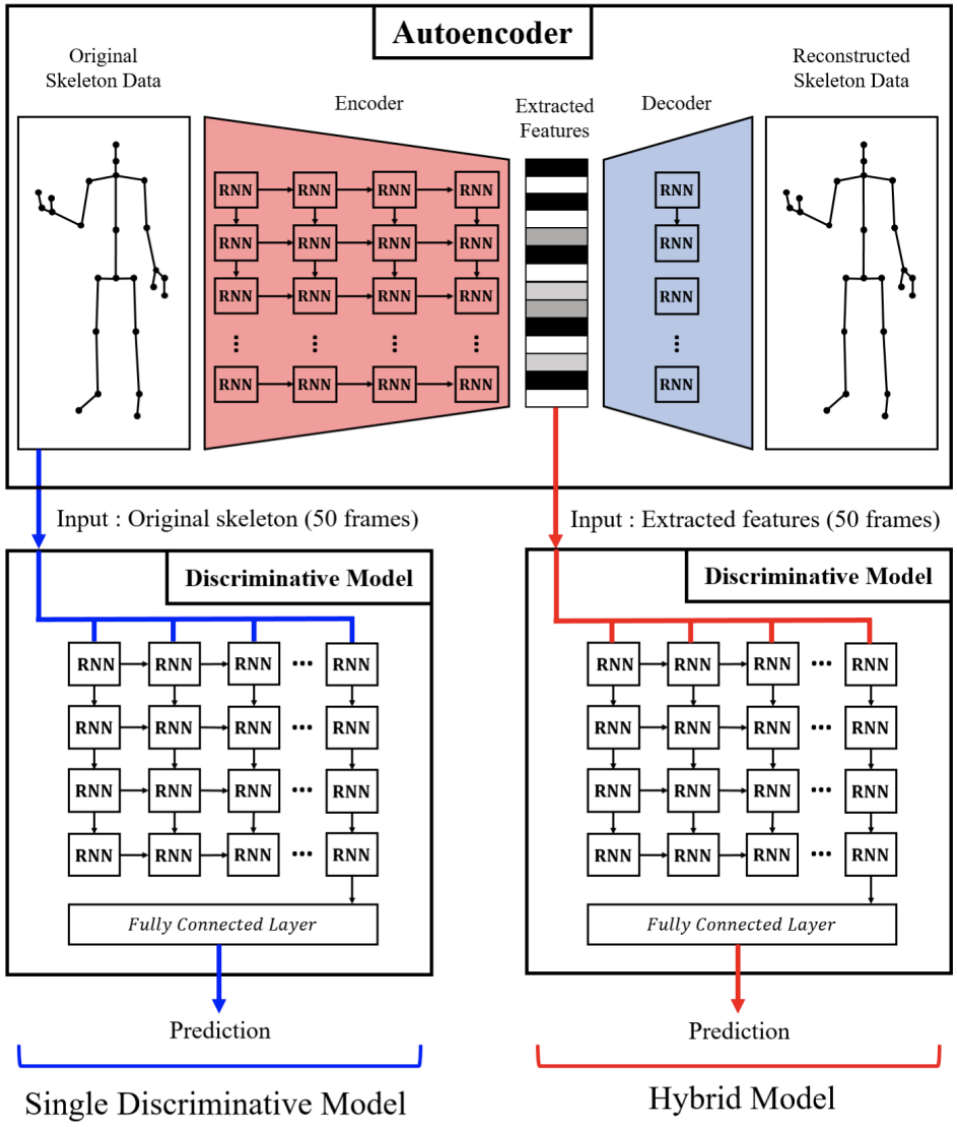
Approach in [Jun20_1]

- RNN with GRU or LSTM cells
- About 90% of accuracy
- Performance are evaluated considering sub-groups of joints



Approach in [Jun20_2]

- RNN with GRU or LSTM cells combined with an RNN autoencoder for feature extraction
- Improvement of about 5% with respect to the previous approach



Possible project developments

- Consider the Sequential skeleton data
- Learning architectures – CNN, RNN…SNN
  - use raw signals with automatic feature extraction or
  - manually extract features or
  - combine the classification network with a preliminary automatic feature extraction network (e.g., autoencoder)
- Average foot pressure data never used by the authors…maybe they can be useful as a side information?
- REMEMBER: this is about sequential data…you cannot perform the classification by considering a single sample (common mistake)

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PROJECT A3

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Project A3 “Motor imagery classification from EEG for brain computer interface”

Reference papers

[Kaya18] Kaya, M., et al. A large electroencephalographic motor imagery dataset for electroencephalographic brain computer interfaces, in Scientific data, vol. 5, no. 1, pp. 1–16, 2018.

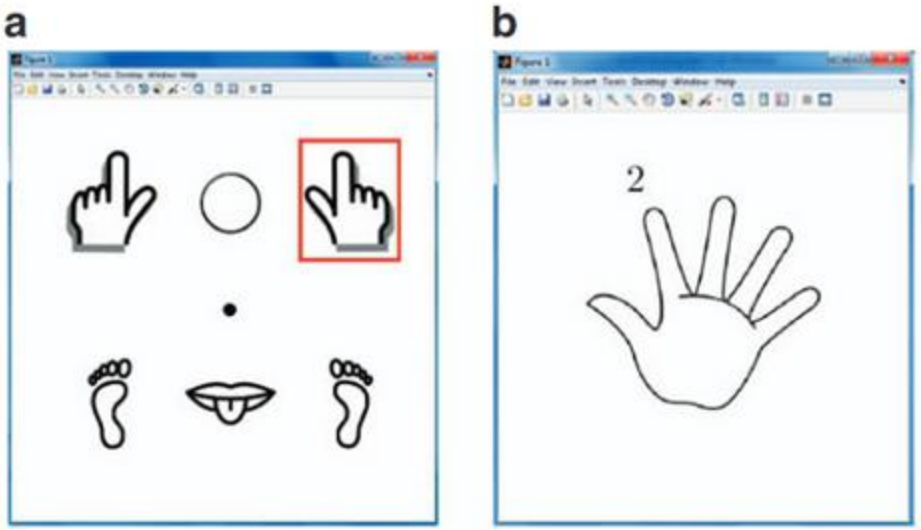
[Altaheri23] H. Altaheri et al., Deep learning techniques for classification of electroencephalogram (EEG) motor imagery (MI) signals: A review, Neural Computing and Applications, vol. 35, no. 20, pp. 14681–14722, 2023.

MI-BCI Dataset (5.3 GB uncompressed)

https://drive.google.com/file/d/1nUTwg3d8_IZKdkwSF5Bb3iYOt7DGbFj4/view?usp=sharing

Dataset description

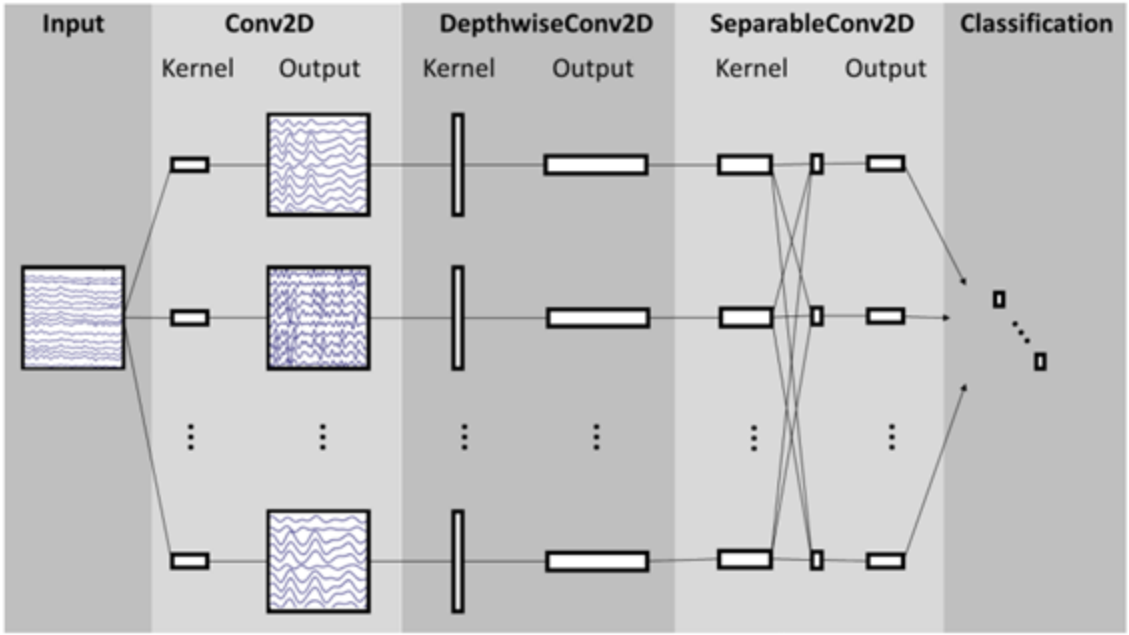
- Largest EEG BCI dataset publicly available
- 60h of EEG recordings from human subjects performing Motor Imagery (MI) tasks
- Sampling rate: 200 Hz and 1000Hz
- 21 active EEG leads
- 13 participants
- 3 different interaction types (paradigms)



1. Left-Right Hand movement
2. Left-Right Hand+Leg+Tongue
3. Individual finger movement (1000Hz)

Approach in [Lawhern18]

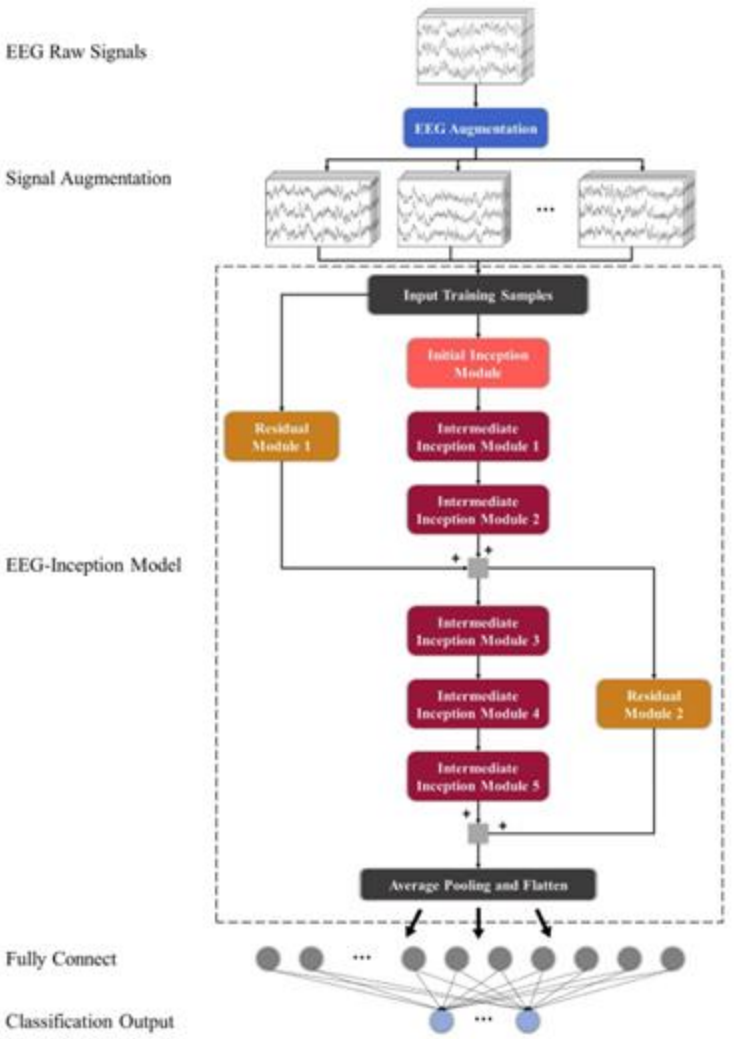
- Compact CNN architecture, one of the most established baseline models for EEG signals
- Exploits both temporal and spatial convolutions to learn frequency filters, and frequency-specific spatial filters



[Lawhern18] V. J. Lawhern, A. J. Solon, N. R. Waytowich, S. M. Gordon, C. P. Hung, and B. J. Lance, EEGNet: a compact convolutional neural network for EEG-based brain–computer interfaces, Journal of neural engineering, vol. 15, no. 5, p. 056013, 2018.

Approach in [Zhang21]

- CNN architecture based on ensemble of multiple inception modules and residual modules
- Data augmentation is used to reduce risk of overfitting
- NB: Study is conducted on a different dataset, so the results are not directly comparable



[Zhang21] C. Zhang, Y.-K. Kim, and A. Eskandarian, EEG-inception: an accurate and robust end-to-end neural network for EEG-based motor imagery classification, Journal of Neural Engineering, vol. 18, no. 4, p. 046014, 2021.

Project proposal

- Classify Motor Imageries (ordered in level of difficulty)
  - Left and Right hand movement, or passive (3 classes)
  - Left and Right hand/leg, tongue and passive (6 classes)
  - Five fingers movement (more challenging) (5 classes)

- Experiment with
  - Different pre-processing techniques (crucial for EEG data)
  - Different data representations (classic feature extraction, spectral representation, etc …)
  - Different architectures (novel, or combinations of existing ones)

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PART B
AUDIO SIGNALS

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Proposed Projects

PART A – ON BODY AND ENVIRONMENTAL SENSORS

1) A1: Activity recognition with four accelerometers
2) A2: Pathological gait recognition
3) A3: Motor imagery classification from EEG for brain computer interface

PART B – AUDIO SIGNALS

1) B1: Speech command recognition (keyword spotting)
2) B2: Environmental sound classification

PART C – IMAGES

1) C1: Sleep posture monitoring
2) C2: Bone age prediction from hand radiographs
3) C3: Lung disease prediction from X-ray images
4) C4: Blood cell type prediction

PART D – RADIO SIGNALS

1) D1: Activity recognition through Wi-Fi devices
2) D2: Gesture recognition through radars

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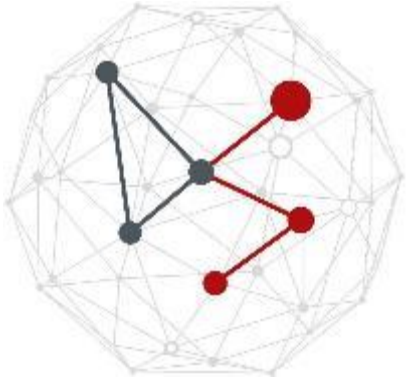
PROJECT B1



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Project B1 “Speech recognition”

Reference papers

[Sainath15] Tara N. Sainath, Carolina Parada, Convolutional Neural Networks for Small-footprint Keyword Spotting, INTERSPEECH, Dresden, Germany, September 2015.

[Warden18] Pete Warden, Speech Commands: A Dataset for Limited-Vocabulary Speech Recognition, arXiv:1804.03209, April 2018.

https://arxiv.org/abs/1804.03209

- The authors are from Google Inc.
- Reference dataset released by Google [Warden18]

Dataset description

- Reference dataset for small-footprint keyword spotting (KWS)
  - Released in August 2017
  - 65,000 one-second-long utterances of 30 words
  - by thousands of different people
  - released under creative commons 4.0 license
  - collected by AIY (https://aiyprojects.withgoogle.com/)

Google blog

https://ai.googleblog.com/2017/08/launching-speech-commands-dataset.html

Speech dataset (2.11 GB uncompressed)

http://download.tensorflow.org/data/speech_commands_v0.02.tar.gz

Approaches for implementing a KWS engine

- **LVCSR based KWS** - This approach uses a two-stage process. In the first stage, the transcription of the speech into words is done using a Large Vocabulary Continuous Speech Recognition (LVCSR) engine, outputting formatted text. In the second stage, a textual search for the key-words within the text is performed. Using this approach, results from LVCSR and the text search are combined to spot the key-words
- **Phoneme Recognition based KWS** - This approach also uses a two-stage process. In the first stage, the speech is transformed to a sequence of phonemes. In the second stage, the application searches for phonetically transcribed key-words in the phoneme sequence obtained from the first stage
- **Word Recognition based KWS** [Sainath15] - This approach searches for the key-words in a one stage operation. The recognition is phoneme-based and the KWS engine looks for the keyword in the speech stream based on a target sequence of phonemes representing the key-word

CNN model from [Sainath15]

- Features are obtained from raw audio data
- 40-dimensional log Mel filterbanks coefficients
  - audio frame length 25 ms
  - with a 10 ms time shift
- At every new audio frame
  - Feature vector is obtained
  - And stacked with 23 frames to the left and 8 to the right (32 frames total)
  - This returns 32 frames at a time, spanning over 31 x 10 ms + 25 ms = 0.335 s
- A Convolutional Neural Network (CNN) is used to detect words
- Input to the CNN is a matrix of size t x n = 32 x 40 = 1,280 elements
  - t represents the number of elements in time (number of audio frames)
  - n represents the number of elements in the frequency domain (Mel features)

CNN model from [Sainath15]

- 27-44% improvement for KWS with respect to traditional neural networks

- The paper focus is on
  - Devising CNN architectures with small memory footprint
  - Playing with CNN parameters (number of kernels, strides, pooling, etc.)

Possible project developments

- Experiment with different audio features
  - Type of coefficients (e.g., discrete Wavelet transform)
  - Design of Mel filterbanks
- Play with a standard/deep CNN using
  - dropout, regularization
- Investigate recent/new ANN architectures
  - Autoencoder-based (CNN/RNN autoencoder + following SVM)
  - Attention mechanism and/or inception-based CNN networks
  - Comparison of different architectures: memory *vs* accuracy

Useful resources

Recent developments

[Chorowski15] J. K. Chorowski, D. Bahdanau, D. Serdyuk, K. Cho, Y. Bengio, Attention-Based Models for Speech Recognition, Conference on Neural Information and Processing Systems (NIPS), Montréal, Canada, 2015.

[Tang18] R. Tang and J. Lin, Deep residual learning for small-footprint keyword spotting, in IEEE ICASSP, Calgary, Alberta, Canada, 2018.

[Andrade18] D. C. de Andrade, S. Leo, M. L. D. S. Viana, and C. Bernkopf, A neural attention model for speech command recognition, arXiv:1808.08929, 2018. https://arxiv.org/pdf/1808.08929.pdf

White Paper: “Key-Word Spotting - The Base Technology for Speech Analytics”

https://pdfs.semanticscholar.org/e736/bc0a0cf1f2d867283343faf63211aef8a10c.pdf

Example code:

https://github.com/tensorflow/tensorflow/tree/master/tensorflow/examples/speech_commands/

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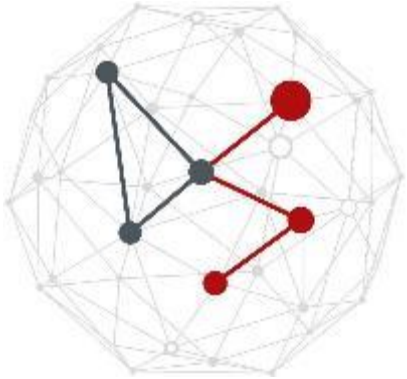
PROJECT B2



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Project B2 “Environmental sound classification”

Reference papers

[Piczak15] K.J. Piczak, ESC: Dataset for Environmental Sound Classification, in Proceedings of the 23rd ACM International Conference on Multimedia, Brisbane, Australia, 2015.

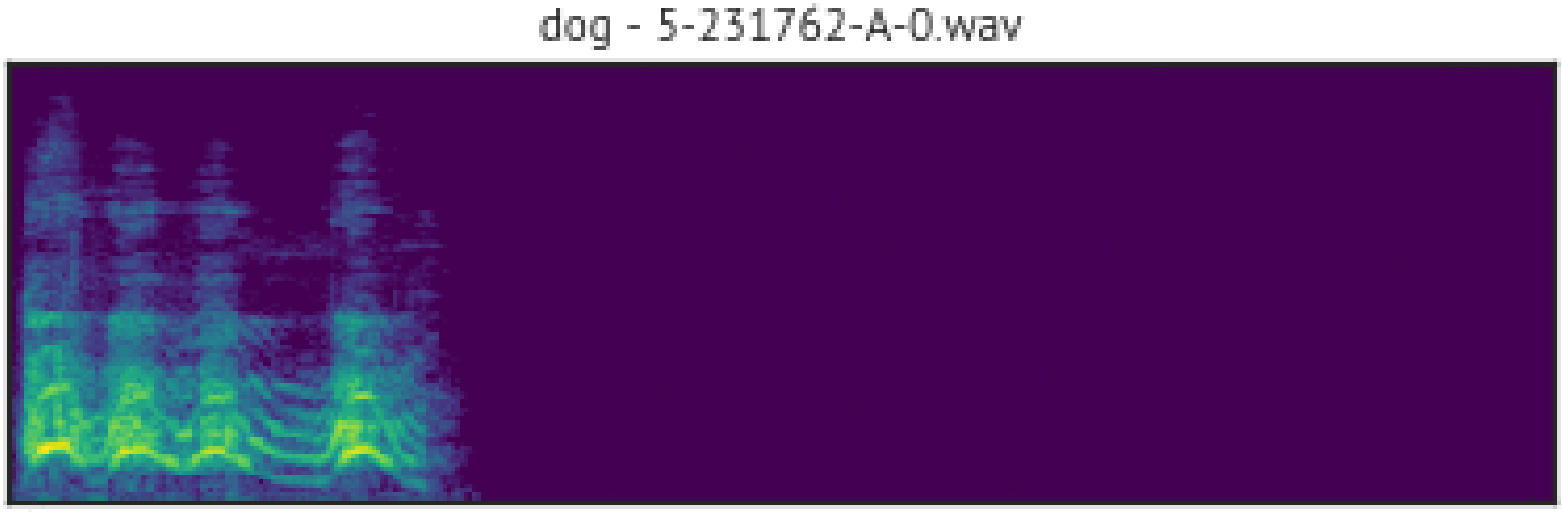
[Piczak15-1] K. J. Piczak, Environmental sound classification with convolutional neural networks, in Proceedings of the IEEE 25th International Workshop on Machine Learning for Signal Processing (MLSP), Boston, MA, 2015.

ECS-50 dataset (884 MB uncompressed)

- https://github.com/karolpiczak/ESC-50
- Annotated collection of 2000 short clips comprising 50 classes of various common sound events

High level description of the dataset

- 5-second-long clips, 44.1 kHz, single channel
- Arranged into 5 uniformly sized cross-validation folds, ensuring that clips originating from the same initial source file are always contained in a single fold



High level description of the dataset

- 50 classes in the dataset

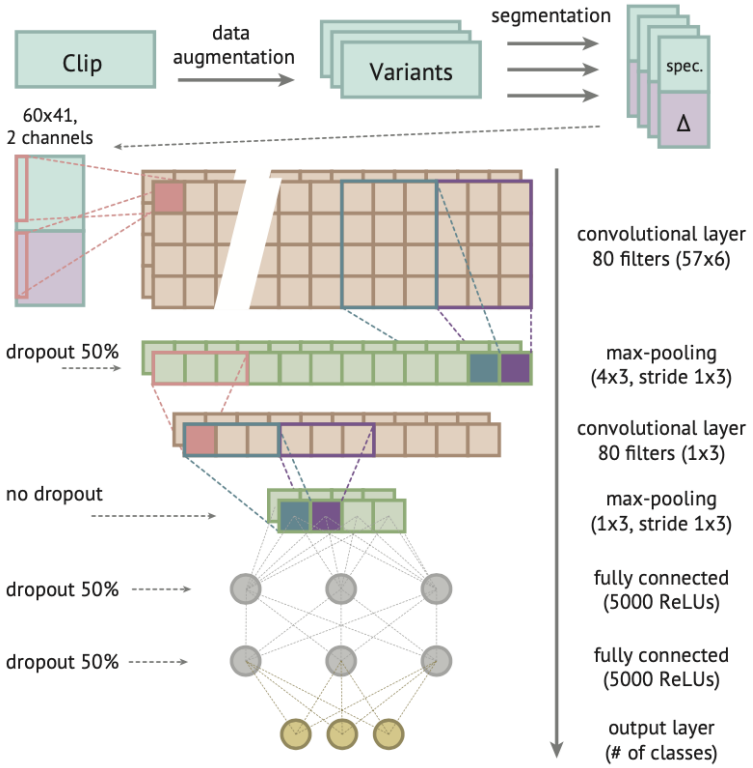
Animals	Natural soundscapes & water sounds	Human, non-speech sounds	Interior/domestic sounds	Exterior/urban noises
Dog	Rain	Crying baby	Door knock	Helicopter
Rooster	Sea waves	Sneezing	Mouse click	Chainsaw
Pig	Crackling fire	Clapping	Keyboard typing	Siren
Cow	Crickets	Breathing	Door, wood creaks	Car horn
Frog	Chirping birds	Coughing	Can opening	Engine
Cat	Water drops	Footsteps	Washing machine	Train
Hen	Wind	Laughing	Vacuum cleaner	Church bells
Insects (flying)	Pouring water	Brushing teeth	Clock alarm	Airplane
Sheep	Toilet flush	Snoring	Clock tick	Fireworks
Crow	Thunderstorm	Drinking, sipping	Glass breaking	Hand saw

High level description of the dataset

- ESC-10: selection of 10 classes from the bigger dataset
  - The differences between classes are much more pronounced, with limited ambiguity
  - Classes: *sneezing, dog barking, clock ticking, crying baby, crowing rooster, rain, sea waves, fire crackling, helicopter, chainsaw*
- meta/esc50.csv data description, the “esc10” column indicates if a given file belongs to the *ESC-10* subset
- meta/esc50-human.xlsx contains the human classification accuracy

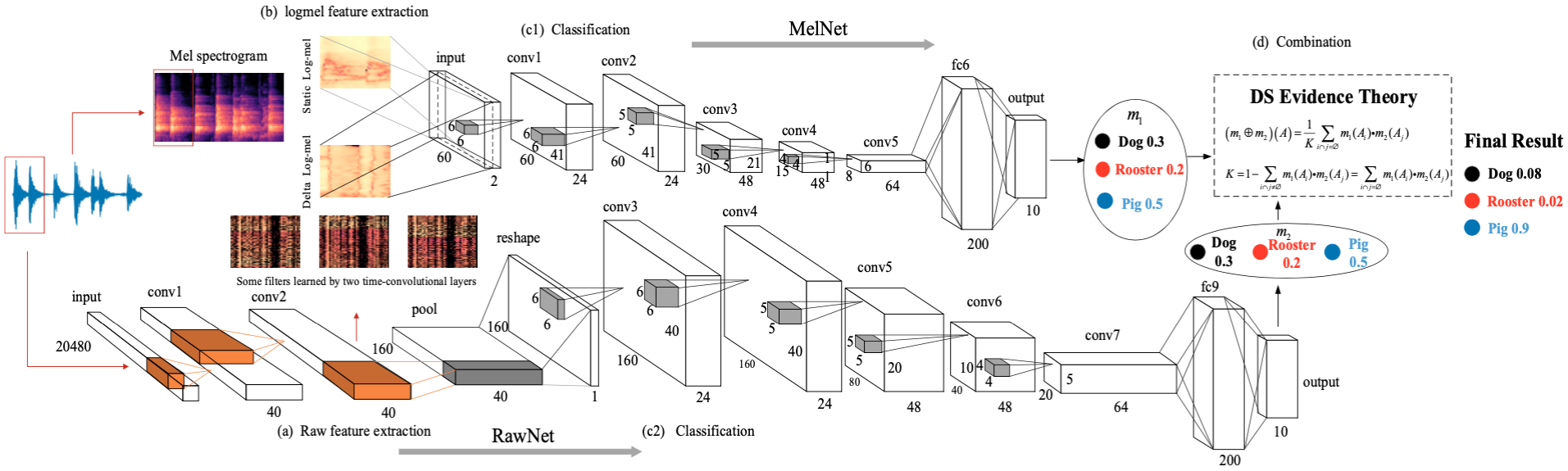
Approach in [Piczak15-1]

- Data augmentation: apply random time delays to the original recordings
- Feature extraction: log-scaled mel-spectrograms with 60 mel-bands
  - resampled to 22,050 Hz
  - windows size 1024
  - hop length 512
- Learning architecture: CNN



Other reference [Li18]

- Combines mel-spectrogram features and raw audio waveform



[Li18] S. Li, Y. Yao, J. Hu, G. Liu, X. Yao and J. Hu, An Ensemble Stacked Convolutional Neural Network Model for Environmental Event Sound Recognition, Applied Science, vol. 8, no. 1152, July 2018.

Useful links

- Some useful functions https://nbviewer.jupyter.org/github/karoldvl/paper-2015-esc-dataset/blob/master/Notebook/ESC-Dataset-for-Environmental-Sound-Classification.ipynb

Possible project developments

- Classification tasks
  - on the entire ESC-50 dataset
  - on the restricted ESC-10 dataset
  - on each of the 5 groups of sounds:
    - animals
    - natural soundscapes & water sounds
    - human, non-speech sounds
    - interior/domestic sounds
    - exterior/urban noises
- Features: try with different approaches: mel-spectrogram, other manual-extracted features, raw data, combinations
- Architectures
  - different possibilities: CNN, RNN, …

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PART C
VISUAL DATASETS

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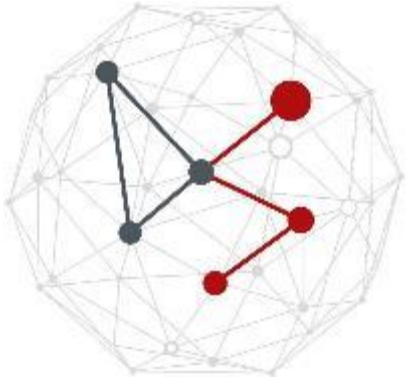
PROJECT C1



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Project C1 “Sleep posture monitoring”

Reference paper

[Pouyan17] M. B. Pouyan, J. Birjandtalab, M. Heydarzadeh, M. Nourani and S. Ostadabbas, A pressure map dataset for posture and subject analytics, in Proceedings of the IEEE EMBS International Conference on Biomedical & Health Informatics (BHI), Orlando, FL, 2017.

PmatData dataset (102.3 MB uncompressed)

https://physionet.org/content/pmd/1.0.0/

Contains in-bed posture pressure data

- multiple adult participants
- two different types of pressure sensing mats

High level description of the dataset

- Pressure data from two separate experiments

Experiment 1: 13 participants

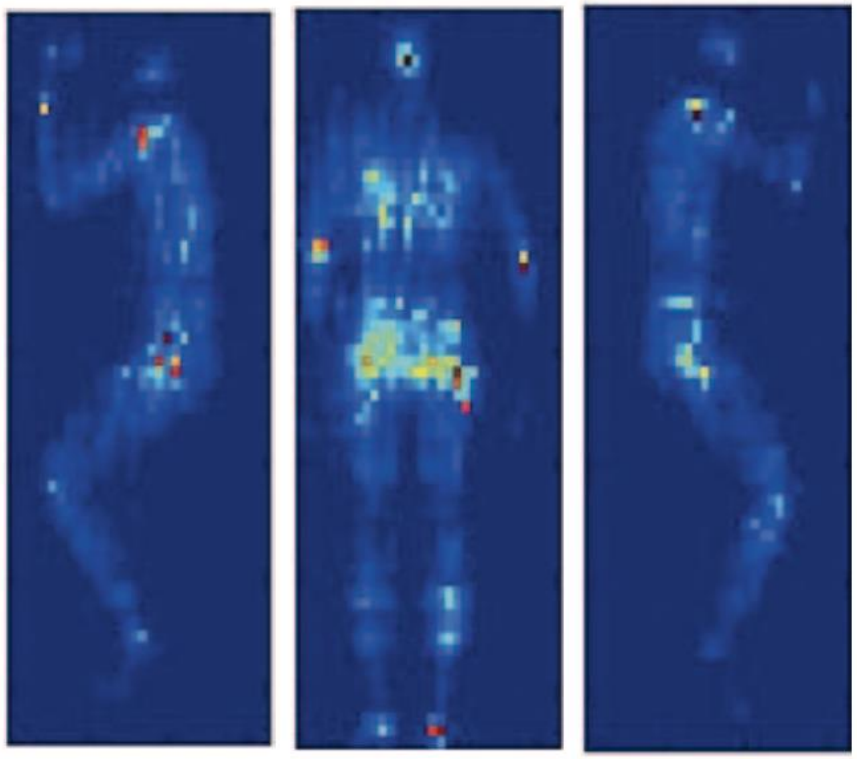
- Size of pressure mat is 32*64: 2048 values per acquisition
- Sampling rate: 1Hz
- Sample values range: [0-1000]
- 17 files for each subject (8 standard postures and 9 additional states)
- Each file includes around 2 minutes of acquisitions

Index	Posture	Bed Inclination (degree)	Body-roll (degree)	Symbol	Duration	Spec's of mat
1	Supine	0	0		2 mins	Vista
2	Right	0	0		2 mins	Vista
3	Left	0	0		2 mins	Vista
4	Right	0	30 (1 wedge)		2 mins	Vista
5	Right	0	60 (2 wedges)		2 mins	Vista
6	Left	0	30 (1 wedge)		2 mins	Vista
7	Left	0	60 (2 wedges)		2 mins	Vista
8	Supine	0	0		2 mins	Vista
9	Supine	0	0		2 mins	Vista
10	Supine	0	0		2 mins	Vista
11	Supine	0	0		2 mins	Vista
12	Supine	0	0		2 mins	Vista
13	Right Fetus	0	0		2 mins	Vista
14	Left Fetus	0	0		2 mins	Vista
15	Supine	30	0		2 mins	Vista
16	Supine	45	0		2 mins	Vista
17	Supine	60	0		2 mins	Vista

High level description of the dataset

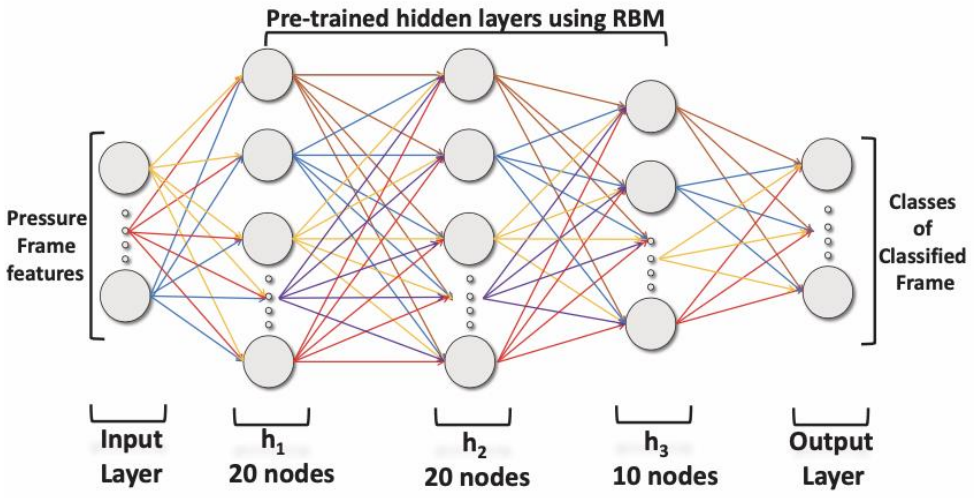
Experiment 2: 8 participants

- The data is collected for both sponge and air mattresses
- Size of pressure mat is 27*64: 1728 values per acquisition
- Each file contains the average of around 20 acquisitions
- 29 different states of 3 standard postures
- Sample values range: [0-500]
- Sampling rate: 1Hz



In [Pouyan17]

- Subject identification in three standard postures:
  1. right side
  2. supine
  3. left side
- Main idea: each subject has a personalized sleeping pattern in each posture
- Architecture: one FFNN for each posture
- Manual feature extraction
  - 18 statistical features



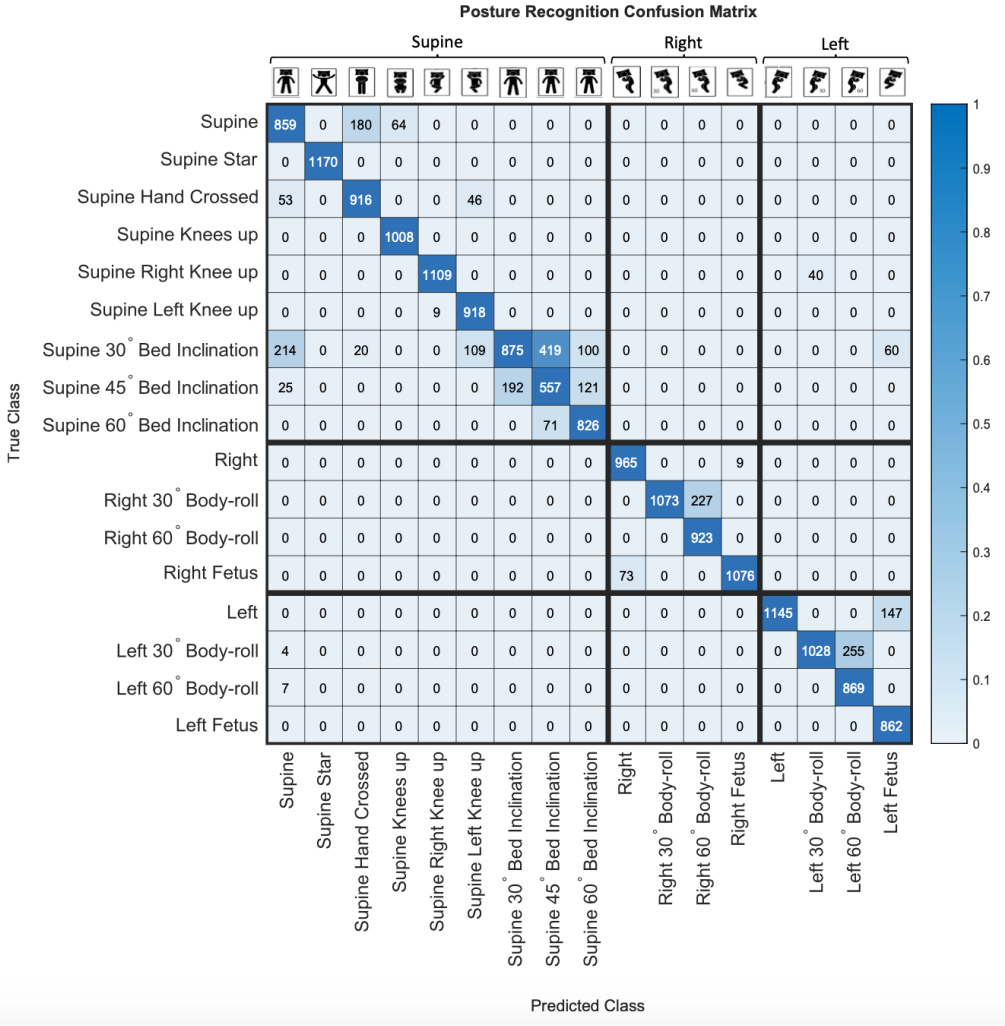
In [Pouyan17]

- Results:

Posture	Predicted/Actual	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13
Supine	Recall	100	90	90	88.8	80	45.4	90	100	90	90	90	80	81.8
	Specificity	100	100	98.3	99.1	99.1	97.6	96.0	96.7	100	99.1	99.1	99.1	100
	Precision	100	100	81.8	88.8	88.8	62.5	64.2	71.4	100	90	80	88.8	100
	Accuracy						85.5							
Right Side	Recall	70	60	80	70	90	90	70	90	100	100	70	60	90
	Specificity	100	98.4	98.3	97.6	95.2	97.5	99.1	100	97.5	98.3	97.6	100	100
	Precision	100	75	72.7	70	60	75	87.5	100	76.9	8.3	70	100	100
	Accuracy						80.4							
Left Side	Recall	33.3	70	100	100	90	81.8	70	100	100	90	80	80	70
	Specificity	100	96.0	96.7	97.5	99.1	98.3	97.5	99.1	98.3	99.1	98.3	98.3	100
	Precision	100	58.3	71.4	76.9	90	75	87.5	90.9	83.3	90	80	80	100
	Accuracy						82.3							
Participants' Details	Age	19	23	23	24	24	26	27	27	30	30	30	33	34
	Height (cm)	175	183	183	177	172	169	179	186	174	174	176	170	174
	Weight (kg)	87	85	100	70	66	83	96	63	74	79	91	78	74

Other reference [Davoodnia19]

- Subject identification and posture recognition using the same data of [Pouyan17]
- Architecture: CNN
- Automatic feature extraction



[Davoodnia19] V. Davoodnia and A. Etemad, Identity and Posture Recognition in Smart Beds with Deep Multitask Learning, in Proceedings of the IEEE International Conference on Systems, Man and Cybernetics (SMC), Bari, Italy, 2019.

Possible project developments

- Classification tasks
  - Subject identification
  - Posture recognition
  - Joint subject identification and posture recognition
- Datasets
  - use one of both the available datasets
  - different mattresses
- Features
  - manual feature extraction or raw data
- Architecture
  - CNN, RNN, combinations… SNN

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PROJECT C2

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Project C2 “Bone age prediction from hand radiographs”

Reference papers

[Larson18] D. B. Larson, M. C. Chen, M. P. Lungren, S. S. Halabi, N. V. Stence, C. P. Langlotz, Performance of a Deep-learning neural network Model in assessing skeletal Maturity on Pediatric hand radiographs, Radiology, vol. 287, no. 1, pp. 313-322, April 2018.

[Halabi19] S. S. Halabi *et al.*, The RSNA Pediatric Bone Age Machine Learning Challenge, Radiology, vol. 290, pp. 498-503, 2019.

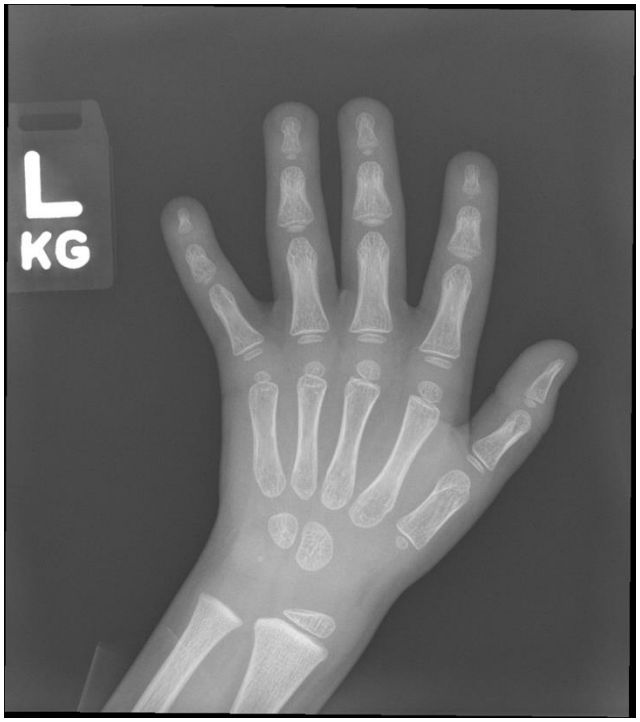
https://www.rsna.org/en/education/ai-resources-and-training/ai-image-challenge/RSNA-Pediatric-Bone-Age-Challenge-2017

Dataset (10.3 GB uncompressed)

https://stanfordmedicine.app.box.com/s/4r1zwio6z6lrzk7zw3fro7ql5mnoupcv/folder/42459416739

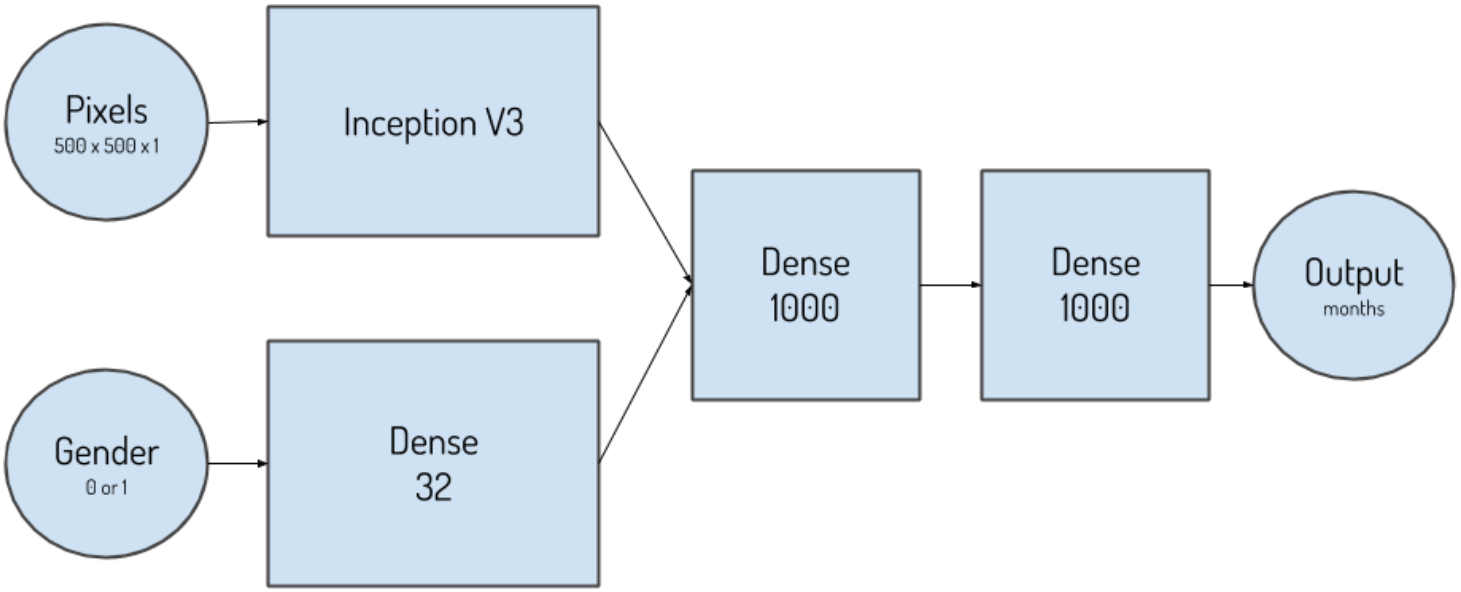
Dataset description

- 12,612 training hands' X-ray images (digital and scanned) from two U.S. hospitals
- CSV file containing the age (to be predicted) and the gender (useful side information)



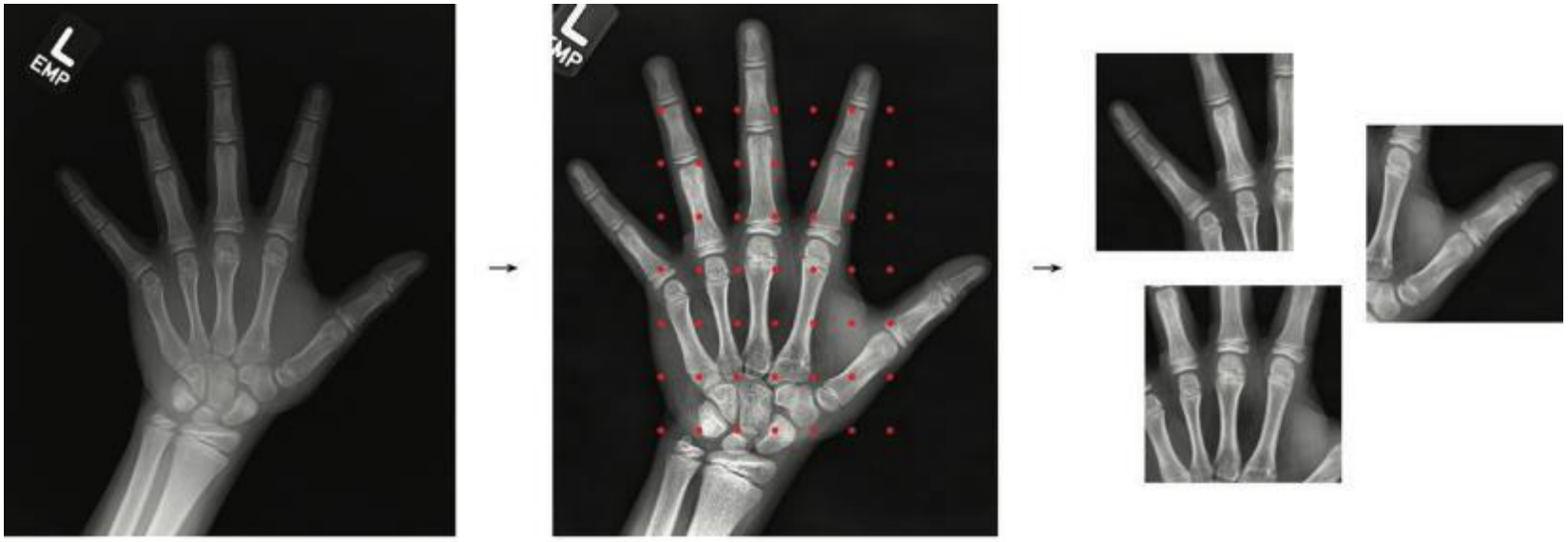
Winner model from [Halabi19]

- https://www.16bit.ai/blog/ml-and-future-of-radiology
- The age is predicted with an accuracy of 4 months



Second-place model from [Halabi19]

- Gender-specific models
- Each image was divided into 49 overlapping patches
- Use ResNet-50



Original Raw Image

Cropped + Resized + CLAHE

Each red point represents the center of an extracted patch.

Each patch is used as a training example for the CNN.

Possible project developments

- Solve the bone age prediction as a regression task
  - as input: use row images or extract features
  - as output: use the age value (for regression)
  - assess the importance of the gender information into the regression
  - possible idea: use the entire image or use subpatches and then apply a decision fusion mechanism
- Architectures
  - different possibilities: CNN, RNN, attention, … SNN

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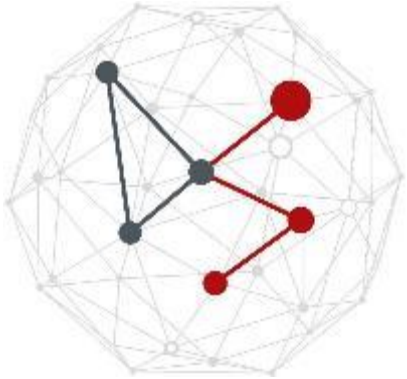
PROJECT C3



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Project C3 “Lung disease prediction from X-ray images”

Reference papers

[Jiancheng2023] Yang, Jiancheng, et al. Medmnist v2-a large-scale lightweight benchmark for 2d and 3d biomedical image classification, Scientific Data 10.1 (2023): 41.

[Xiaosong2017] Wang, Xiaosong, et al. Chestx-ray8: Hospital-scale chest x-ray database and benchmarks on weakly-supervised classification and localization of common thorax diseases, Proceedings of the IEEE conference on computer vision and pattern recognition. 2017.

Dataset (2 GB uncompressed)

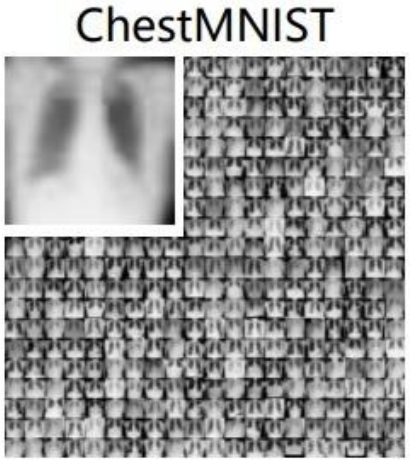
https://medmnist.com/ dataset+code

https://zenodo.org/records/10519652 download the chestMNIST dataset

Three versions: image sizes 1x64x64, 1x128x128, and 1x224x224

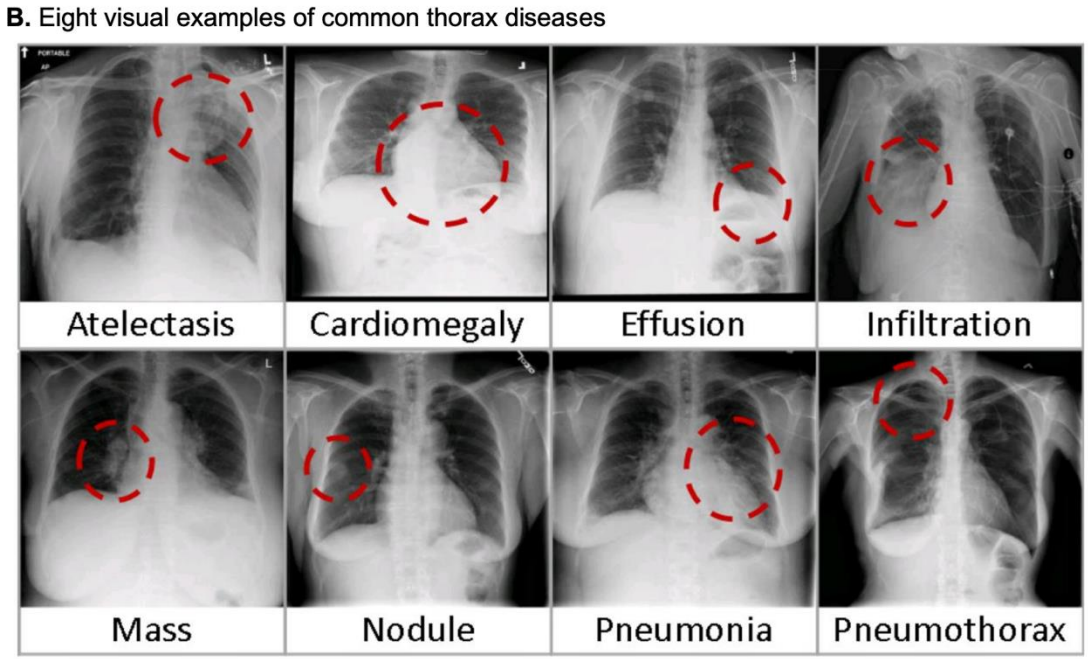
Dataset description

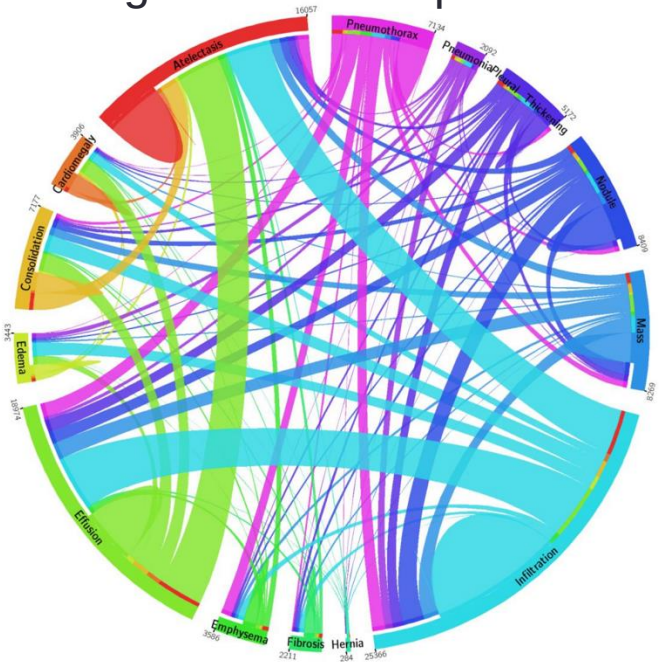
- 112,120 frontal X-ray images
- 30,805 unique patients
- 14 different classes of diseases



MedMNIST2D	Data Modality	Tasks (# Classes/Labels)	# Samples	# Training / Validation / Test
ChestMNIST	Chest X-Ray	Multi-Label (14) Binary-Class (2)	112,120	78,468 / 11,219 / 22,433

some images have multiple labels





Approach in [Xiaosong2017]

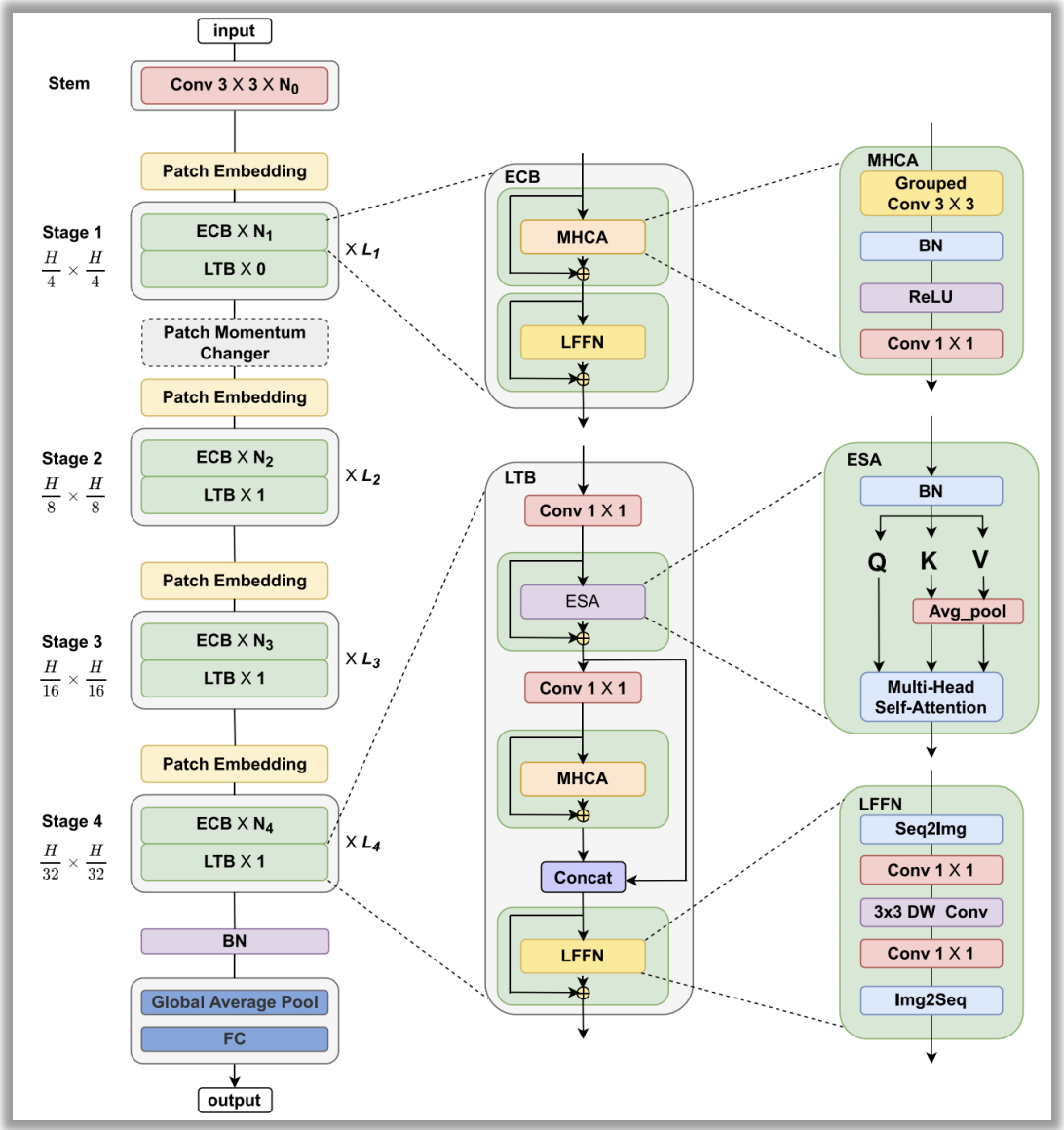
- Classification considering 8 classes
- 4 different pre-trained models: AlexNet, GoogLeNet, VGG and ResNet-50

Setting	Atelectasis	Cardiomegaly	Effusion	Infiltration	Mass	Nodule	Pneumonia	Pneumothorax
Initialization with different pre-trained models								
AlexNet	0.6458	0.6925	0.6642	0.6041	**0.5644**	0.6487	0.5493	0.7425
GoogLeNet	0.6307	0.7056	0.6876	0.6088	0.5363	0.5579	0.5990	0.7824
VGGNet-16	0.6281	0.7084	0.6502	0.5896	0.5103	0.6556	0.5100	0.7516
ResNet-50	**0.7069**	**0.8141**	**0.7362**	**0.6128**	0.5609	**0.7164**	**0.6333**	**0.7891**
Different multi-label loss functions								
CEL	0.7064	0.7262	0.7351	0.6084	0.5530	0.6545	0.5164	0.7665
W-CEL	0.7069	0.8141	0.7362	0.6128	0.5609	0.7164	0.6333	0.7891

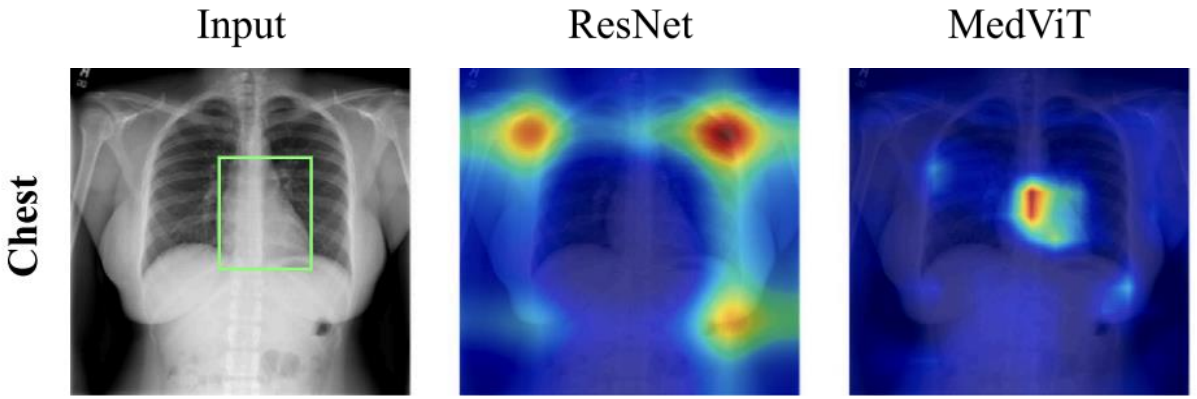
Table 3. *AUCs of ROC curves for multi-label classification in different DCNN model setting.*

Approach in [Jiancheng2023]

- MedViT: composed of a patch embedding layer, transformer blocks and a series of stacked convolution in each stage



Approach in [Jiancheng2023]



Methods	ChestMNIST	
	AUC	ACC
ResNet-18 (28) [20]	0.768	0.947
ResNet-18 (224) [20]	0.773	0.947
ResNet-50 (28) [20]	0.769	0.947
ResNet-50 (224) [20]	0.773	0.948
auto-sklearn [75]	0.649	0.779
AutoKeras [76]	0.742	0.937
Google AutoML [77]	0.778	0.948
MedVIT-T (224)	0.786	0.956
MedVIT-S (224)	0.791	0.954
MedVIT-L (224)	0.805	0.959

Possible project developments

- Classification task
  - use row images or extract features
  - use the 8 classes considered in [Xiaosong2017] or 14 classes as done in [Jiancheng2023]
  - try with different image sizes (64x64, 128x128, 224x224)
  - possible approaches: classify the entire image or use subpatches and then apply a decision fusion mechanism
  - use attention mechanisms
  - use spiking neural networks

- Architectures
  - CNN, RNN, attention, …

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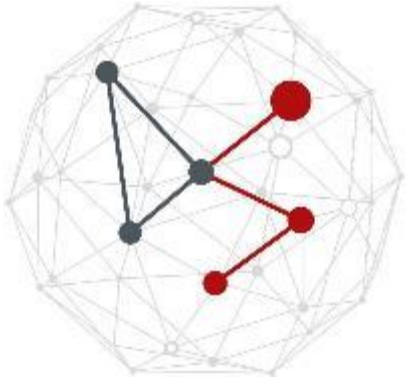
PROJECT C4



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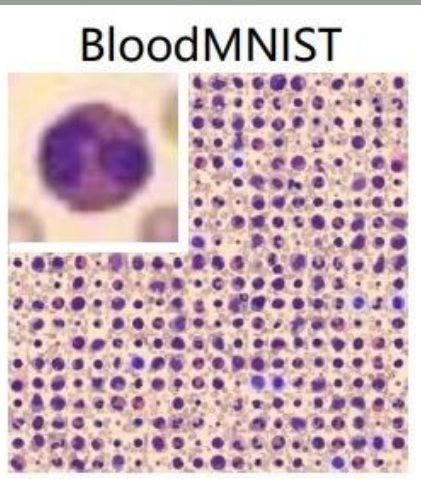


Project C4 “blood cell type prediction”

Reference papers

[Jiancheng2023] Yang, Jiancheng, et al. Medmnist v2-a large-scale lightweight benchmark for 2d and 3d biomedical image classification, Scientific Data 10.1 (2023): 41.

[Acevedo2020] Acevedo, A. et al. A dataset of microscopic peripheral blood cell images for development of automatic recognition systems. Data Brief 30, 105474, (2020).

Dataset (2 GB uncompressed)

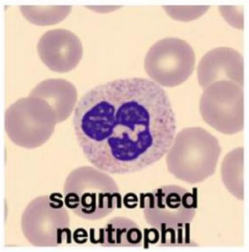
https://medmnist.com/ dataset+code

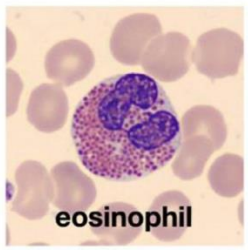
https://zenodo.org/records/10519652 download the bloodMNIST dataset

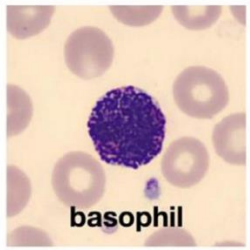
Three versions: image sizes 3x64x64, 3x128x128, and3x 224x224

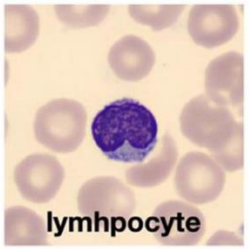
Dataset description

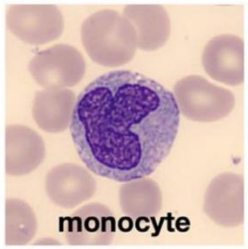
- 17,092 images of individual normal cells
- 8 different classes

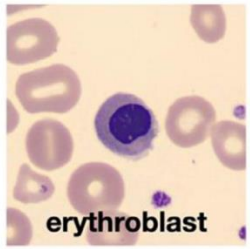








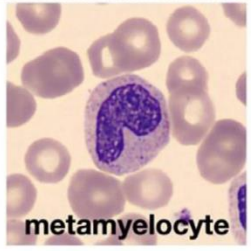


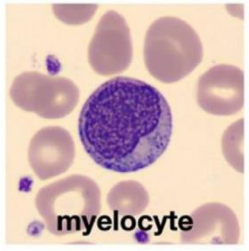


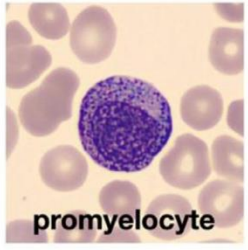
MedMNIST2D	Data Modality	Tasks (# Classes/Labels)	# Samples	# Training / Validation / Test
BloodMNIST	Blood Cell Microscope	Multi-Class (8)	17,092	11,959 / 1,712 / 3,421

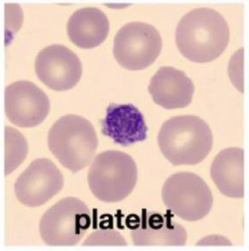
Types and number of cells in each group.

CELL TYPE	TOTAL OF IMAGES BY TYPE	%
neutrophils	3329	19.48
eosinophils	3117	18.24
basophils	1218	7.13
lymphocytes	1214	7.10
monocytes	1420	8.31
immature granulocytes (metamyelocytes, myelocytes and promyelocytes)	2895	16.94
erythroblasts	1551	9.07
platelets (thrombocytes)	2348	13.74
Total	17,092	100



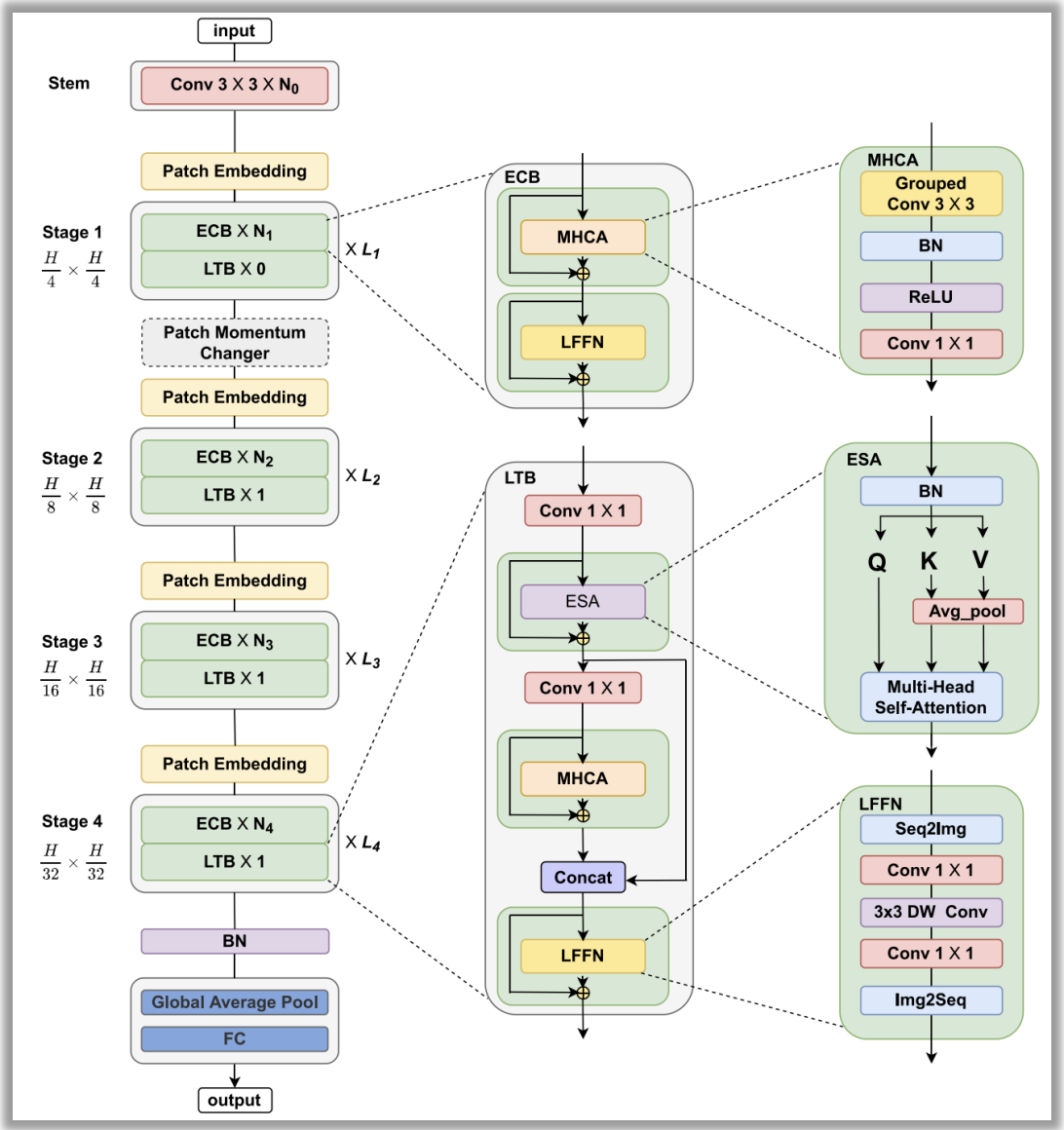






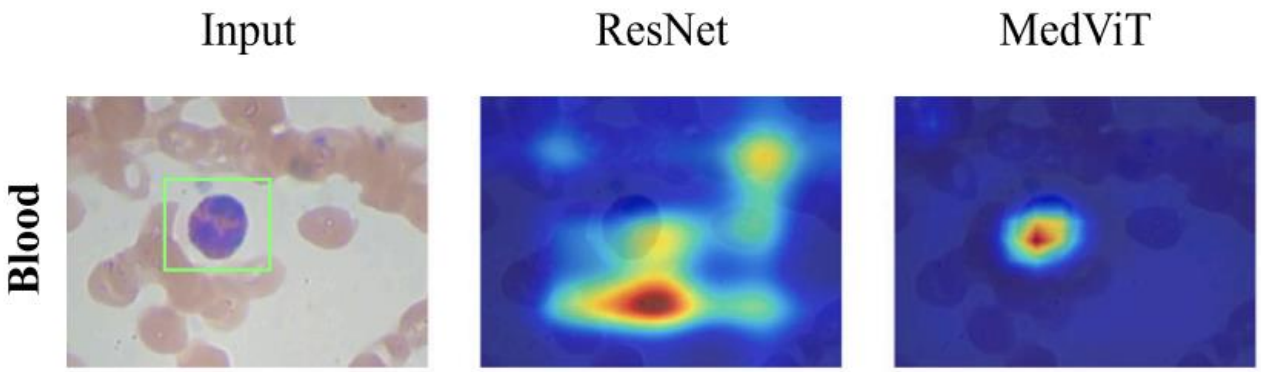
Approach in [Jiancheng2023]

- MedViT: composed of a patch embedding layer, transformer blocks and a series of stacked convolution in each stage

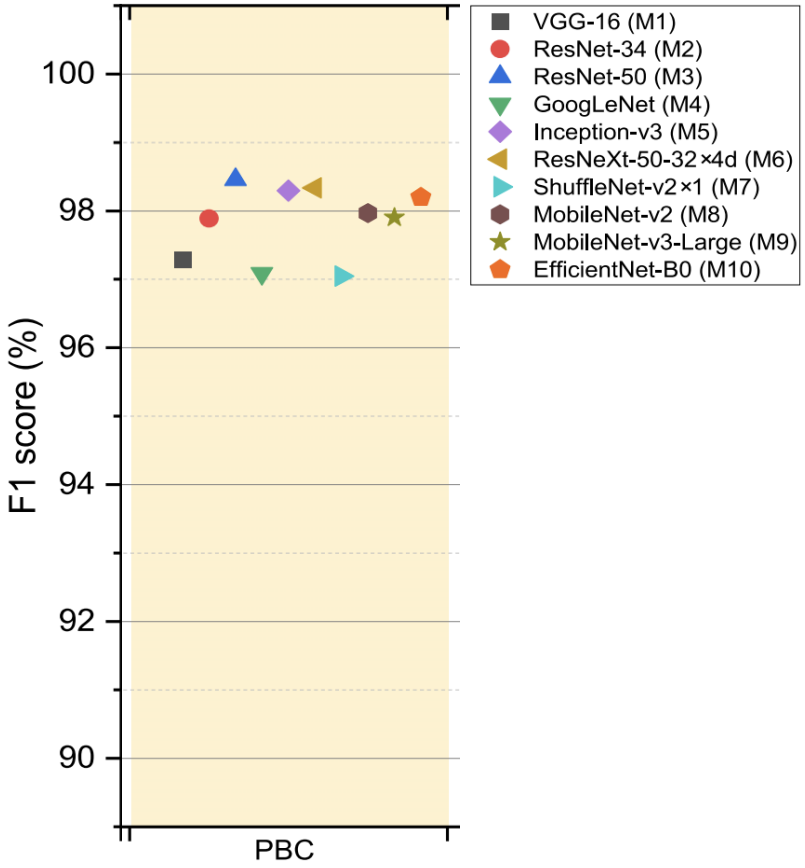


Approach in [Jiancheng2023]

Methods	BloodMNIST	
	AUC	ACC
ResNet-18 (28) [20]	0.998	0.958
ResNet-18 (224) [20]	0.998	0.963
ResNet-50 (28) [20]	0.997	0.956
ResNet-50 (224) [20]	0.997	0.950
auto-sklearn [75]	0.984	0.878
AutoKeras [76]	0.998	0.961
Google AutoML [77]	0.998	0.966
MedVIT-T (224)	0.996	0.950
MedVIT-S (224)	0.997	0.951
MedVIT-L (224)	0.996	0.954



Approach in [Rui2022]



PBC	
Methods	**Accuracy**
Acevedo et al. [35]	96.2%
Bagido et al. [36]	98.4%
Long et al. [67]	**99.3%**
Proposed	98.46%

Check the referenced papers for their approaches

[Rui2022] Liu, Rui, et al. AIMIC: Deep learning for microscopic image classification. *Computer Methods and Programs in Biomedicine* 226 (2022): 107162.

Possible project developments

- Classification task
  - use row images or extract features
  - try with different image sizes (3x64x64, 3x128x128, 3x224x224)
  - possible approaches: classify the entire image or use subpatches and then apply a decision fusion mechanism
  - use attention mechanisms
  - use spiking neural networks

- Architectures
  - CNN, RNN, attention, …

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PART D
WIRELESS SIGNALS

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Proposed Projects

PART A – ON BODY AND ENVIRONMENTAL SENSORS

1) A1: Activity recognition with four accelerometers
2) A2: Pathological gait recognition
3) A3: Motor imagery classification from EEG for brain computer interface

PART B – AUDIO SIGNALS

1) B1: Speech command recognition (keyword spotting)
2) B2: Environmental sound classification

PART C – IMAGES

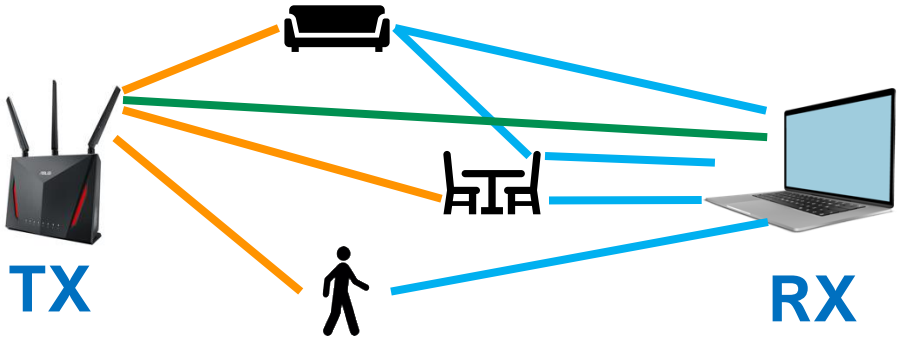
1) C1: Sleep posture monitoring
2) C2: Bone age prediction from hand radiographs
3) C3: Lung disease prediction from X-ray images
4) C4: Blood cell type prediction

PART D – RADIO SIGNALS

1) D1: Activity recognition through Wi-Fi devices
2) D2: Gesture recognition through radars

General idea

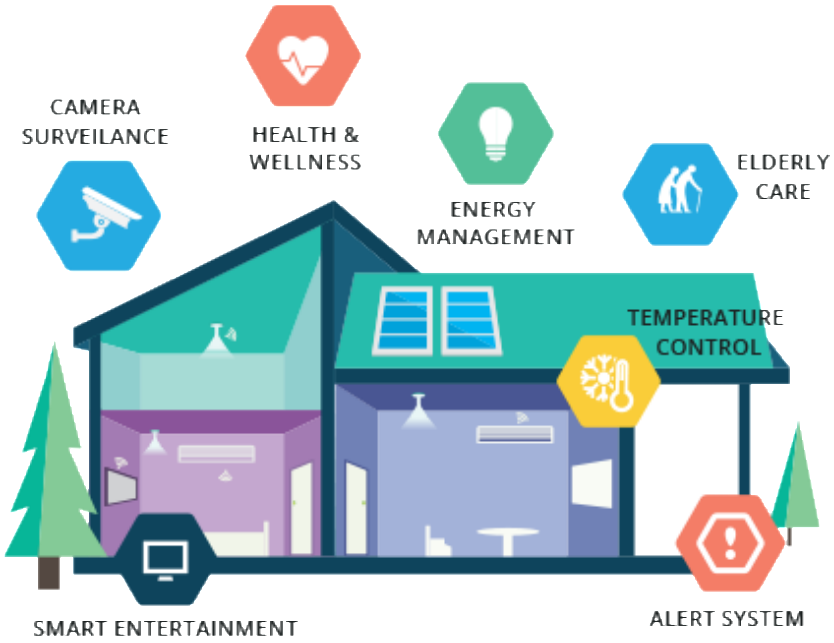
- **Main idea.** The presence and the movement of objects in the environment affect the Wi-Fi signal (multi-path) propagation
- These modifications can be
  - estimated via dedicated signal processing on the Wi-Fi channel frequency response (CFR) and
  - used as a proxy for human sensing applications



General idea

- Why radio waves for sensing?
  - more user friendly than approaches based on wearable devices: the user is not required to wear anything
  - privacy preserving: no images of the subjects are captured
  - insensitive to light conditions and the presence of dust, smoke
  - see through walls/obstacles (low frequencies)

- Applications
  - Human detection
  - Fall detection
  - Human activity recognition
  - Human vital signs monitoring
  - People tracking
  - Gesture recognition



General idea

- In recent years, spurred by the pervasiveness of Wi-Fi-enabled devices, Wi-Fi sensing has been widely investigated
- September 2020: the IEEE 802.11bf working group was established to empower Wi-Fi devices with sensing capabilities [Meneghello2023]
- The goal is to allow Wi-Fi routers to perform a dual role
  - communication access points (AP)
  - monitoring devices, leveraging ongoing Wi-Fi traffic as well as ad-hoc packets to deliver the sensing service

[Meneghello2023] F Meneghello, C Chen, C Cordeiro, F Restuccia, Toward Integrated Sensing and Communications in IEEE 802.11 bf Wi-Fi Networks. *IEEE Communications Magazine*, 2023.

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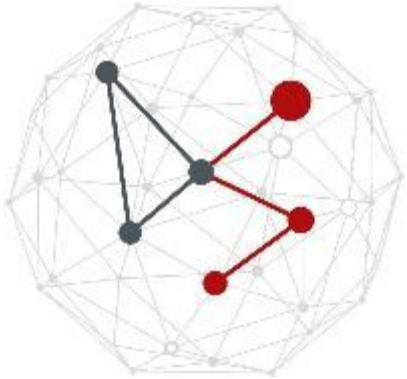
PROJECT D1



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Project D1 “Activity recognition through Wi-Fi channel frequency response”

Reference paper

[Meneghello2022] F. Meneghello, D. Garlisi, N. D. Fabbro, I. Tinnirello and M. Rossi, SHARP: Environment and Person Independent Activity Recognition with Commodity IEEE 802.11 Access Points. *IEEE Transactions on Mobile Computing*. 2022.

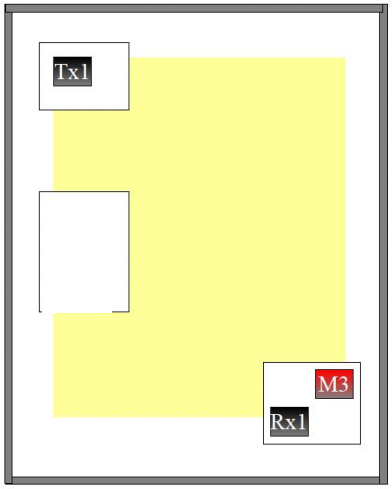
Dataset (23 GB uncompressed) – **AR-** sub-folders

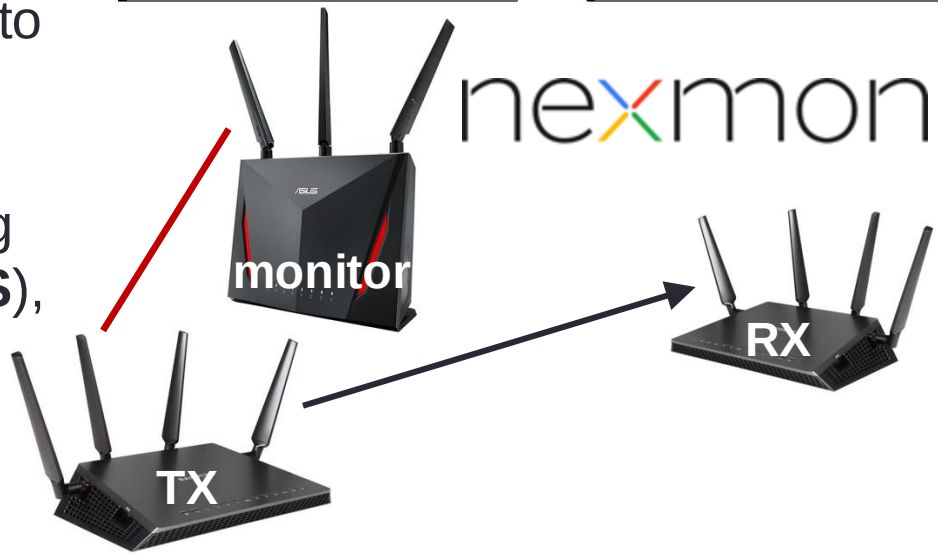
https://drive.google.com/file/d/1t9wrxCyk1_AqXj3j_NQ81tNzwOdhH1j1/view?usp=sharing

https://ieee-dataport.org/documents/csi-dataset-wireless-human-sensing-80-mhz-wi-fi-channels

Dataset description

- More than 6 hours of Wi-Fi channel readings acquired while a volunteer (4 in total) performs up to six different activities in different indoor environments
- Walking (**W**), running (**R**), jumping (**J**), sitting still (**L**), standing still (**S**), sitting down/standing up (**C**) and doing arm exercises (**G**)





set	campaigns	environment	w × l × h [m]	obstructed path	devices pos.	Tx hardware	Rx hardware	person, Pi
AR-1	a-b-c-d-e	bedroom	5 × 6 × 4	-	M1-Tx-Rx	Netgear	Netgear	P1
AR-2	a	bedroom	5 × 6 × 4	-	M1-Tx-Rx	Netgear	Netgear	P2
AR-3	a-b	bedroom	5 × 6 × 4	✓	M2-Tx-Rx	Netgear	Netgear	P1
AR-4	a	bedroom	5 × 6 × 4	✓	M2-Tx-Rx	Netgear	Netgear	P2
AR-5	a-b	living room	5 × 6 × 4	-	M3-Tx1-Rx1	Netgear	Netgear	P1
AR-6	a	kitchen	3.5 × 3 × 3.2	-	M3-Tx1-Rx1	Netgear	Netgear	P1
AR-7	a	laboratory	7.5 × 3.5 × 2.9	-	M3-Tx1-Rx1	Netgear	Netgear	P3
AR-8	a-b	office	4 × 6 × 3	-	M3-Tx1-Rx1	Asus	Asus	P4
AR-9	a-b-c	semi-anechoic	9 × 7 × 3.4	-	M3-Tx1-Rx1	Asus	Asus	P4

Dataset description (also for D2, D3)

- For each pair of transmit and receive antennas, the CFR consists of a vector of complex numbers specifying the attenuation and the phase shift experienced by the signal over each OFDM sub-channel
- Each .mat file collects the *M* CFR vectors (referred to as a CFR trace) acquired during the transmission time
- The CFR trace is saved as a $(N * Nant)$ X *M* dimensional complex matrix, where each row is a CFR vector
- The CFR vectors estimated on different monitor antennas are stored as subsequent rows in the CFR trace

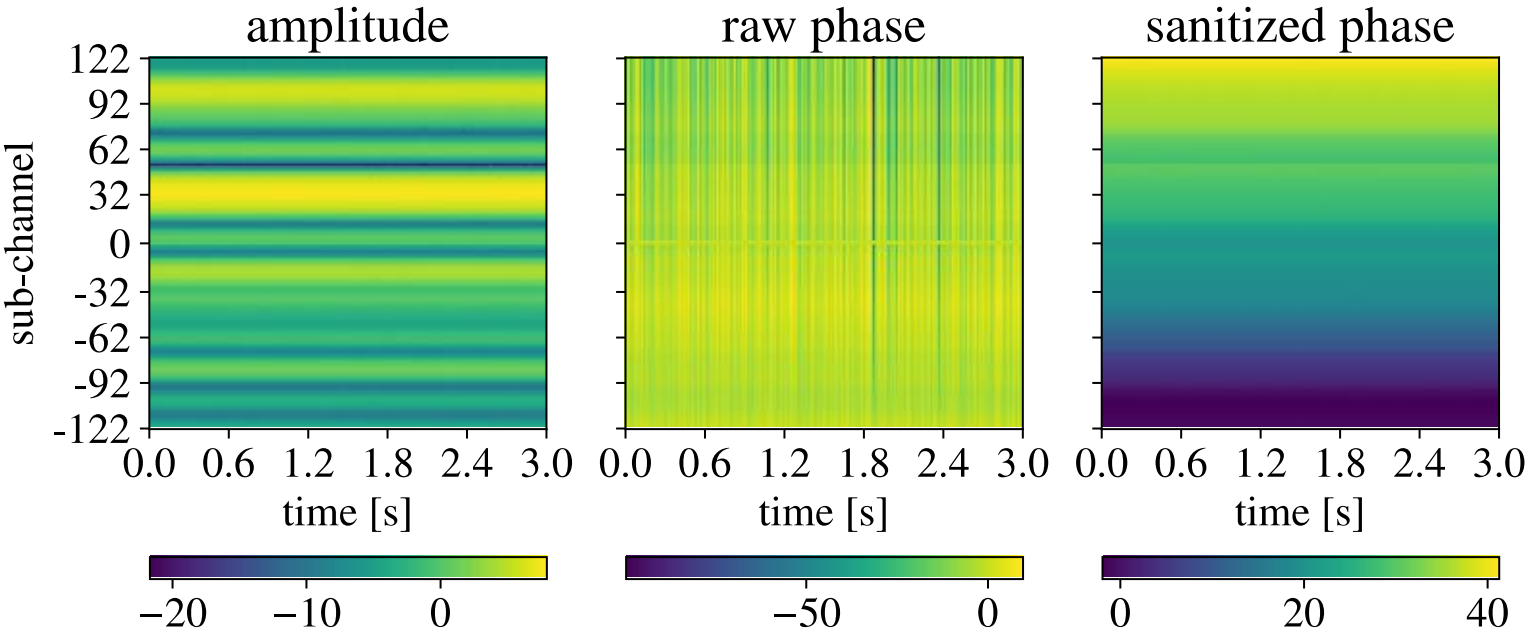
Dataset description

- A Python script is available at https://github.com/signetlabdei/SHARP to process the data and obtain an *M* X *N* X *Nant*-dimensional matrix → more convenient

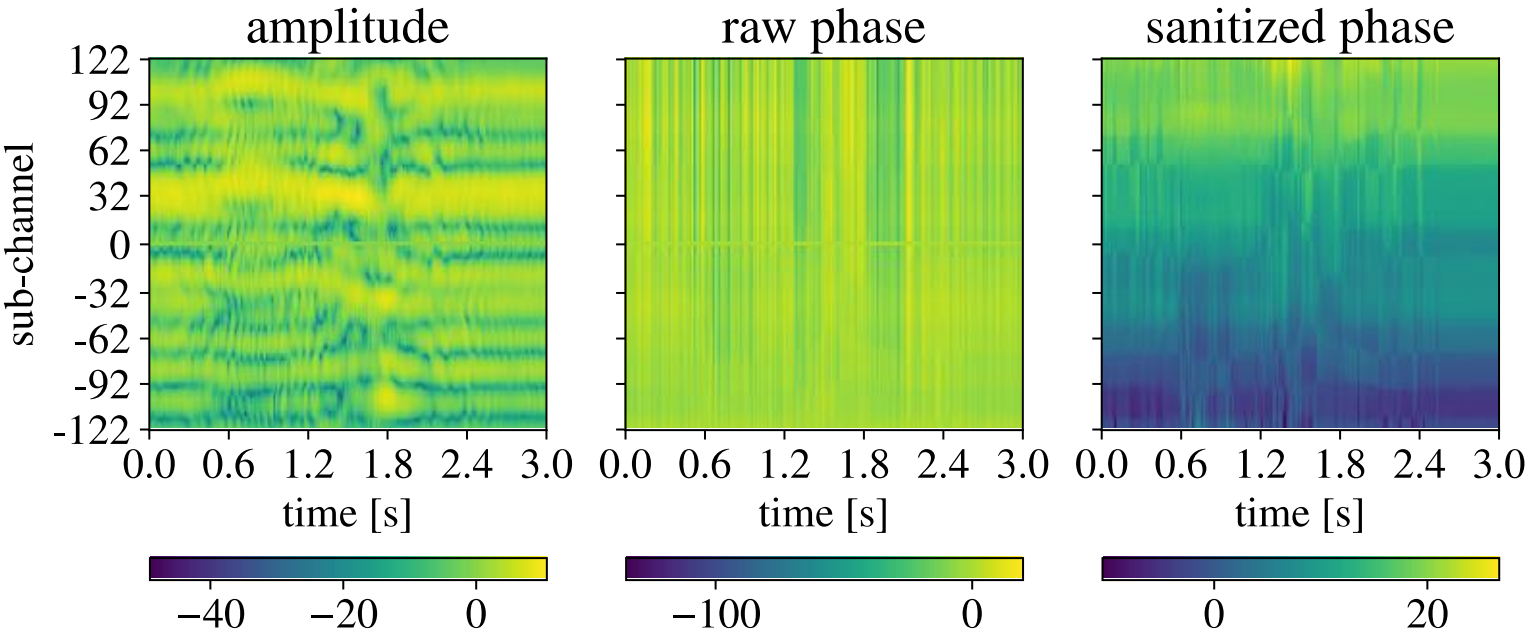
- The repository also contains Python scripts to
  - invert the sign on sub-channels from −63 to 122 (artifact introduced by the Nexmon tool)
  - sanitize the CFR phase to remove the phase offsets introduced in the CFR recordings due to hardware artifacts

- The CFR can also be sanitized by considering one antenna as a reference and multiplying the CFR on the other antennas by the complex conjugate CFR of the reference antenna → ok if you use the raw amplitude and phase, but not so good if you want to leverage Doppler

empty room

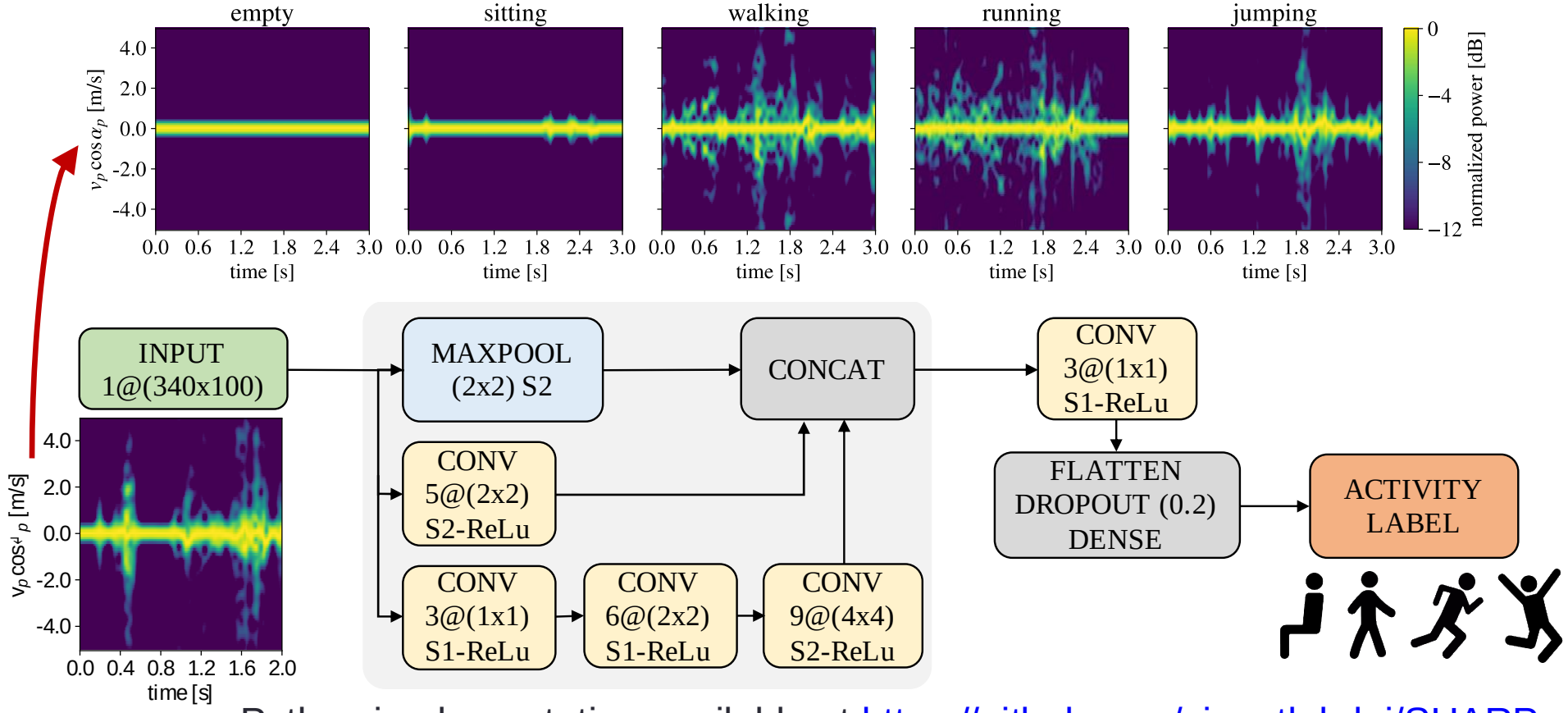


running person



Approach in [Meneghello2022]

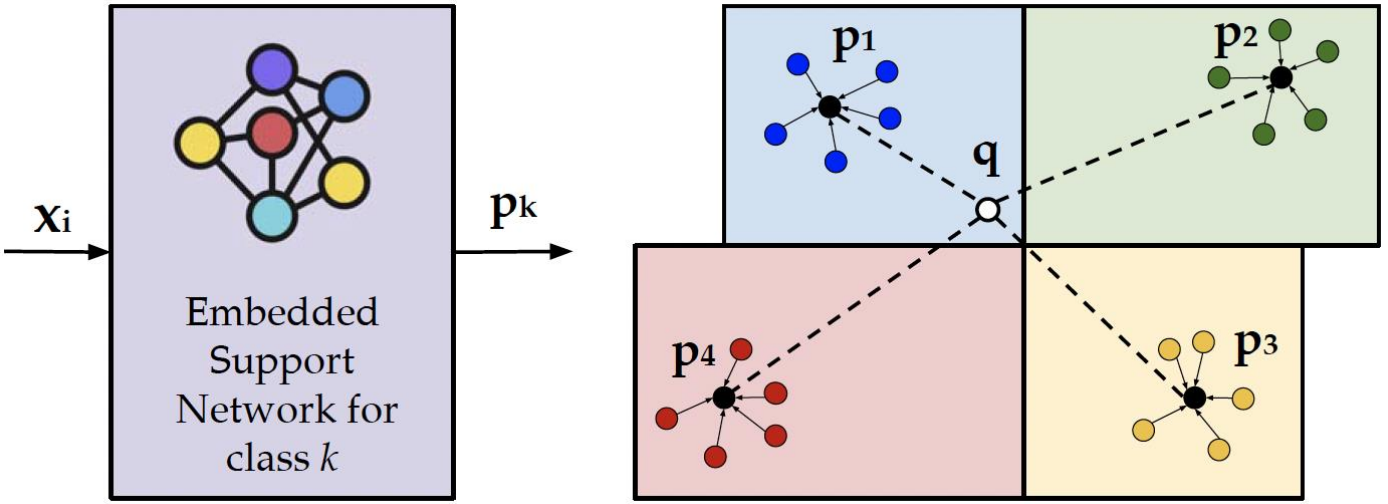
- Estimate the Doppler shift from the channel frequency response
- Use a CNN-based algorithm to classify the activities



Python implementation available at https://github.com/signetlabdei/SHARP

Approach in [Bahadori2022]

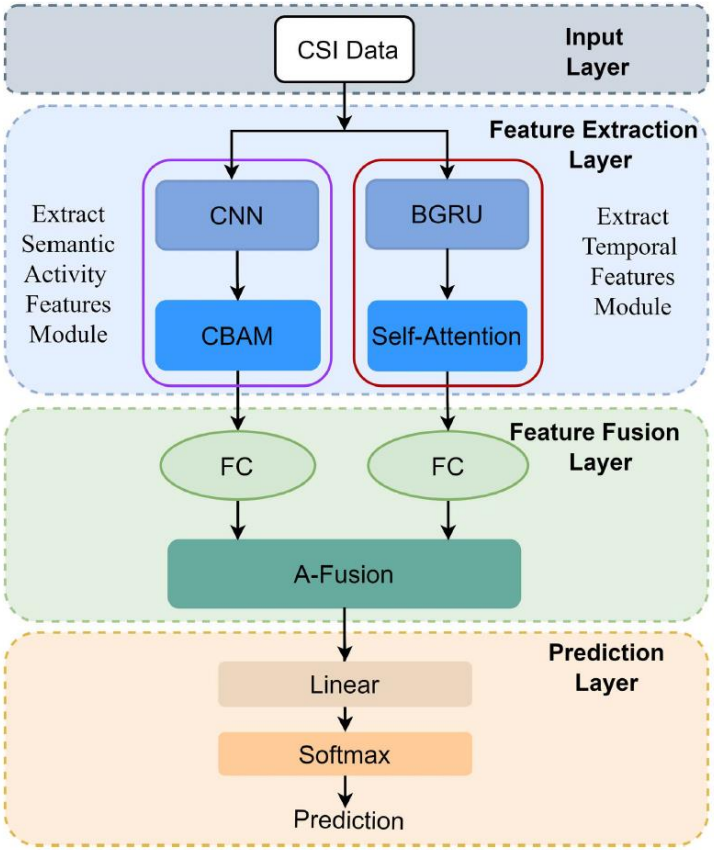
- Embedded prototype network - few-shot learning
  - can generalize to new environments by leveraging only a few new samples



Implementation available at https://github.com/niloobah/ReWiS

[Bahadori2022] N. Bahadori, J. Ashdown, and F. Restuccia, ReWiS: Reliable Wi-Fi Sensing Through Few-Shot Multi-Antenna Multi-Receiver CSI Learning. *in Proc. of IEEE WoWMoM*, 2022

Approach in [Zhang2022]



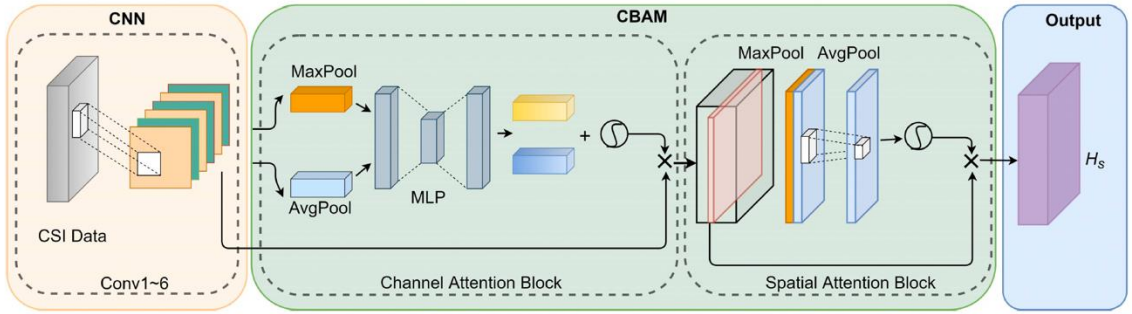


Fig. 6. Structure of semantic activity features extraction module.

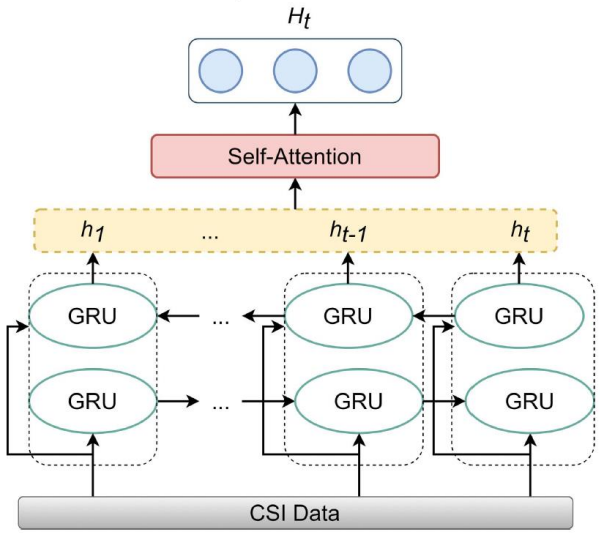
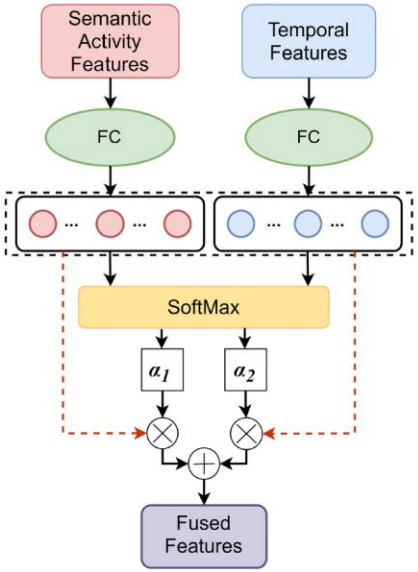


Fig. 7. Structure of temporal features extraction module.



Structure of A-Fusion.

[Zhang2022] Y. Zhang, Q. Liu, Y. Wang and G. Yu, CSI-Based Location-Independent Human Activity Recognition Using Feature Fusion. *IEEE Transactions on Instrumentation and Measurement*, vol. 71, pp. 1-12, 2022

Possible project developments

- Classification task
  - try different approaches to obtain robust algorithms, i.e., that work well when tested on different environments, people and hardware with respect to the ones considered during training
  - use different features as input: raw data (CFR amplitude and/or phase), processed features (Doppler shift or others), combinations of them…
  - try networks with memory cells (recurrent) to capture the correlation in time
  - try including attention mechanisms to capture relevant characteristics of different movements
  - compare the approaches in [Meneghello2022] and [Bahadori2022] on the same dataset/datasets (you can also train in one of the datasets and test on the other)

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Master's degree ICT Internet Multimedia Engineering

PROJECT D2

DIPARTIMENTO DI INGEGNERIA DELL'INFORMAZIONE

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UNIVERSITÀ DEGLI STUDI DI PADOVA

Project D2 “Gesture recognition through radars”

Reference papers

[Wang2016] S. Wang, J. Song, J. Lien, I. Poupyrev, O. Hilliges, Interacting with soli: Exploring fine-grained dynamic gesture recognition in the radio-frequency spectrum. Proceedings of the 29th Annual Symposium on User Interface Software and Technology, 851-860, 2016.

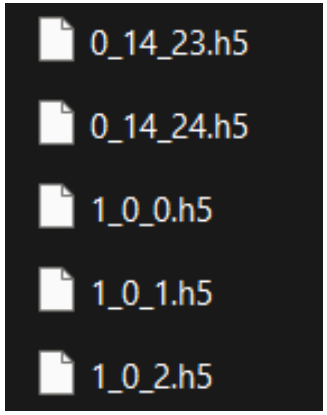
[Tsang2021] I.J. Tsang, F. Corradi, M. Sifalakis, W. Van Leekwijck, S. Latré, Radar-Based Hand Gesture Recognition Using Spiking Neural Networks. Electronics 2021, 10, 1405.

Dataset (8.56 GB uncompressed)

Soli dataset

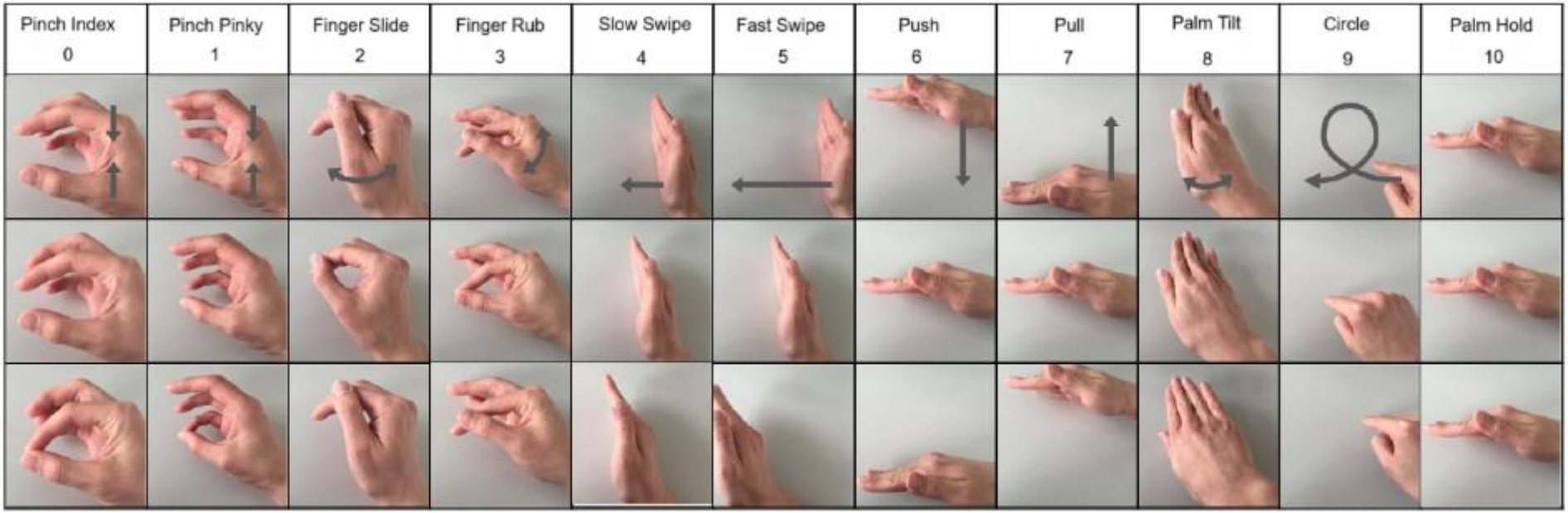
Dataset description

- The Soli dataset is based on the dynamic gesture signals collected by a millimeter-wave radar
- Each data array has shape [number of frames] x 1024 (can be reshaped back to 2D Range-Doppler images with shape 32 x 32)
- 11 gestures
- 10 users
- File names in the dataset folder are defined as [gesture ID]_[session ID]_[instance ID].h5
- Sequences with gesture ID 11 are background signals with no presence of hand



Dataset description

- The 11 gestures are listed in the image below
- Each column represents one gesture, and for each of them, three important steps are reported



Dataset description

- Dataset session arrangement for evaluation:
  - 11 (gestures) * 25 (instances) * 10 (users) = 2750 sequences

    for cross-user evaluation

    [session 2 (25), 3 (25), 5 (25), 6 (25), 8 (25), 9 (25), 10 (25), 11 (25), 12 (25), 13 (25)]

  - 11 (gestures) * (50 (instances) * 4 (sessions) + 25 (instances) * 2 (sessions)) = 2750 sequences

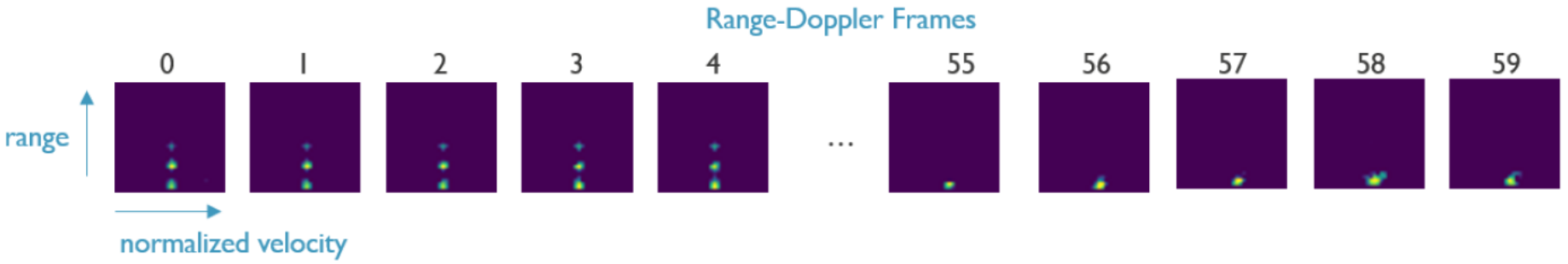
    to evaluate cross-session performance and to explore personalized gesture recognition

    [session 0 (50), 1 (50), 4 (50), 7 (50), 13 (25), 14 (25)]

- Total of 2750 + 2750 = 5500 sequences

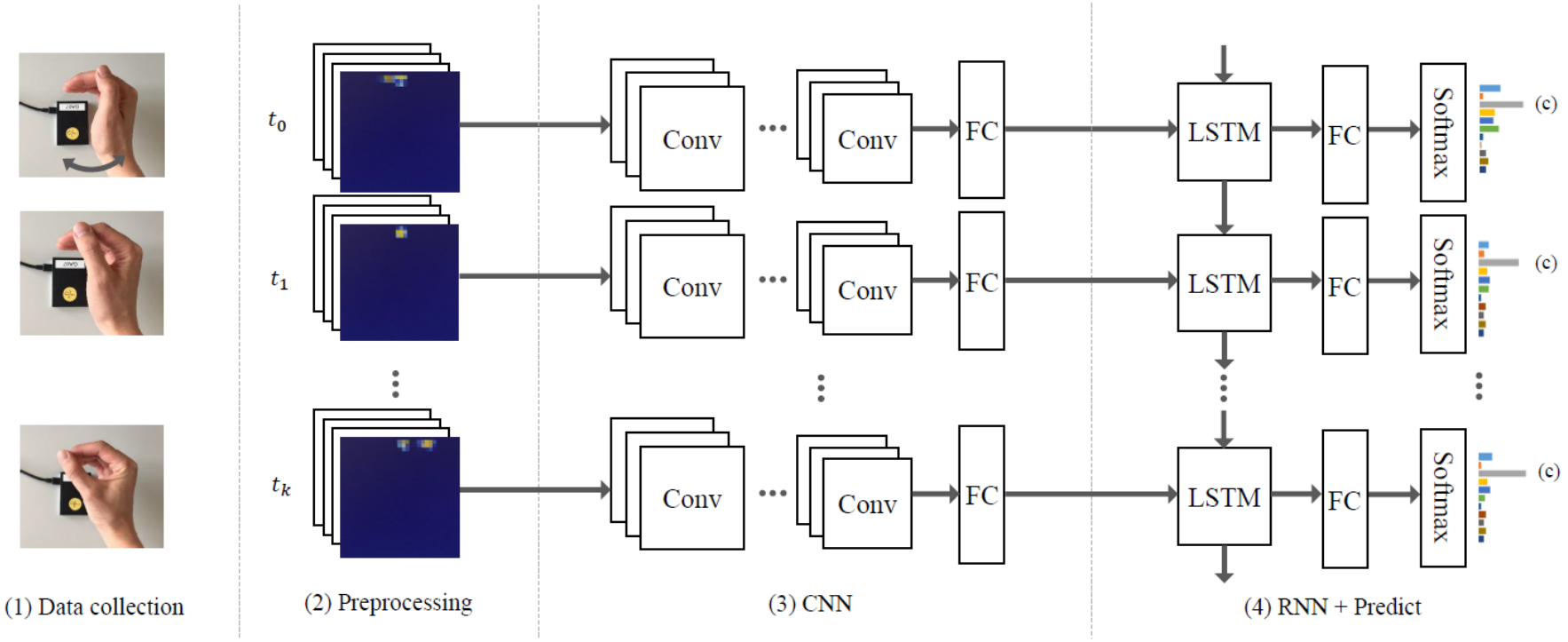
Approach in [Wang2016]

- Dataset pre-processing: background removal (using a per-pixel Gaussian model) + signal normalization
- Input to the model: set of consecutive Range-Doppler frames (stacked)



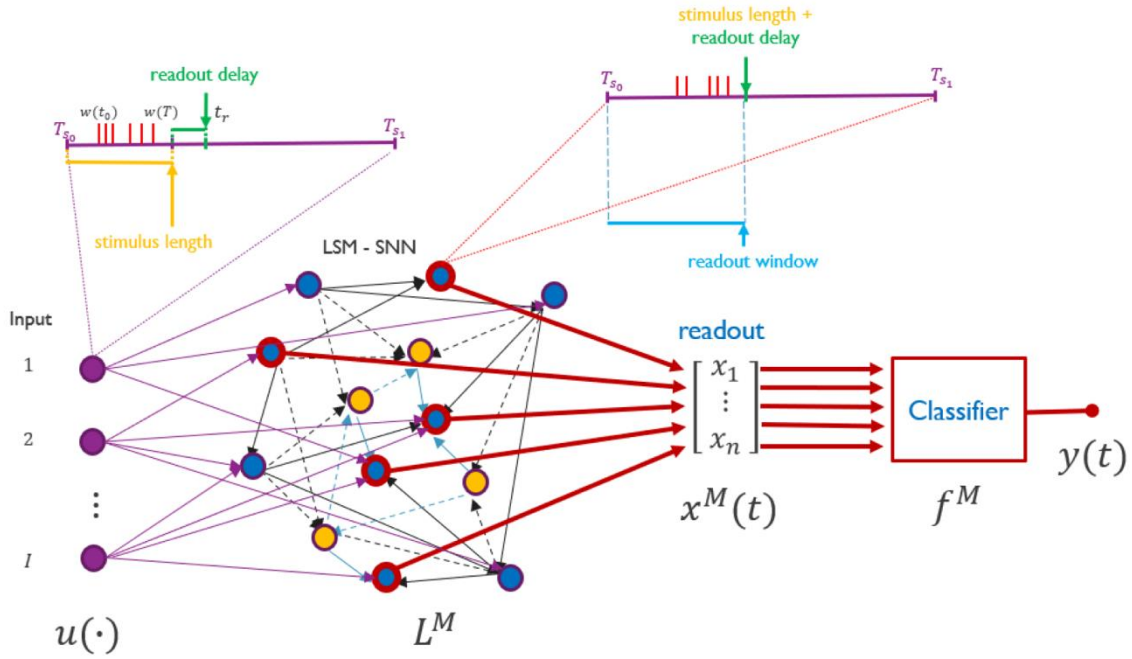
Approach in [Wang2016]

- Architecture composed of a CNN and an RNN stacked and jointly trained
- The final gesture recognition accuracy is used as optimization criterion
- Average accuracy of 87.17%



Approach in [Tsang21]

- Use of a Liquid State Machine (LSM), which is a type of reservoir computing (see [Maass2004]) that uses spiking neurons, followed by a readout map to perform the classification
- The authors used 3 different classifiers for comparison: logistic regression, random forest, and support vector machine



[Maass2004] W. Maass, H. Markram, On the computational power of circuits of spiking neurons, Journal of Computer and System Sciences, Volume 69, Issue 4, 2004.

Approach in [Tsang21]

- The liquid is composed of excitatory (E) and inhibitory (I) neurons, with 20% configured as inhibitory
- The synaptic connections are randomly assigned, creating a sparse network with the following ratios: EE=2, EI=2, IE=1, and II=1
- The Range-Doppler frames are encoded into spike trains, prior to feeding them to the LSM

Project proposal

- Classification of the 11 gestures
- Architectures
  - Non-spiking
    - Experiment with different hyper-parameters for both CNN and RNN (num. of layers, kernel size, type of recurrent units…)
    - Explore different features learning techniques (e.g., an CNN-based Autoencoder)
  - Spiking
    - Explore different configurations of the LSM (proportion of inhibitory neurons, synaptic connections…)
    - Explore different spike encoding techniques for the input data
    - Explore different architectures (e.g., fully SNN architectures with LIF neurons, using surrogate gradient approach)

Master's degree ICT Internet Multimedia Engineering

MACHINE LEARNING FOR HUMAN DATA – FINAL EXAMINATION

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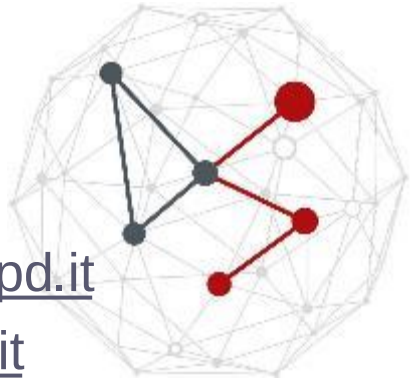

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