NEXT GEN + SMART HOME

From Radar to Physiological Signal

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PROBLEM STATEMENT

- The Japanese home developer Sekisui House has partnered with MIT Device Realization Lab to develop smart homes for Japan's aging population
- Sekisui House plans to integrate radar sensors into residential ceilings for non-intrusive monitoring of vital signs like heart rate and respiration rate
- Our job is to develop a model that combines traditional signal processing with neural networks, to accurately derive vital signs from radar data
- Our model will be part of a comprehensive system that predicts movements and habits and detects abnormal activities for timely medical assistance

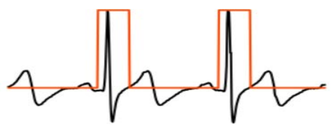
MODEL 1

Predict heart / respiration rate per minute

72 heart beats per minute | 16 breathes per minute

MODEL 2

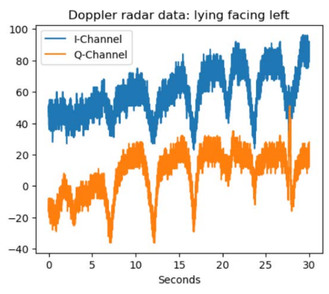
Predict timestamp of each heart pulse

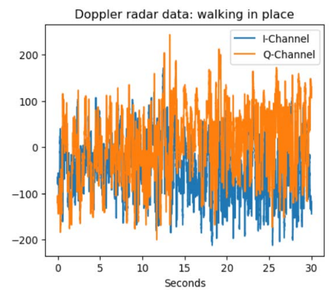


DATA OVERVIEW

Input: Doppler Radar Signals

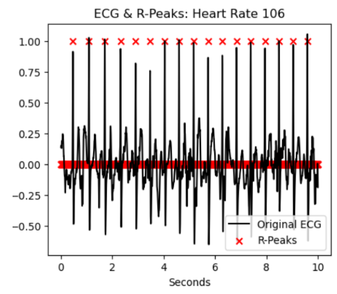
- Measurement frequency: 1000 Hz
- I & Q channels: I channel detects velocity and acceleration; Q channel records direction changes
- Noise: the radar captures everything from pronounced activities like walking to subtle movements of heart pulse, even capturing the flutter of air particles
- Actions: Stationary actions result in extended periodicity; pronounced movements render the radar signal more chaotic and inconsistent

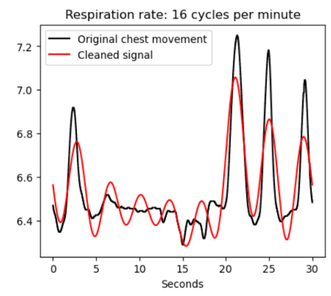




Ground Truth: Heart / Chest Signals

- Measurement frequency: 250 Hz
- Heart: records the movement of each heart pulse like an electrocardiogram (ECG)
- Heart rate: we developed a double find peak algorithm to derive the heart rate from ECG signal
- Respiration: chest movement; irregular subject to larger measurement error
- Respiration rate: we developed a signal processing algorithm, using small samples from larger clips to clean chest signals and derive respiration rate





SOLUTION METHODOLOGY

Data mapping → Radar signal to heart and respiration data (30 second clips)

Extract ground truth labels → Derive heart / respiration rate and position of heart pulse peaks

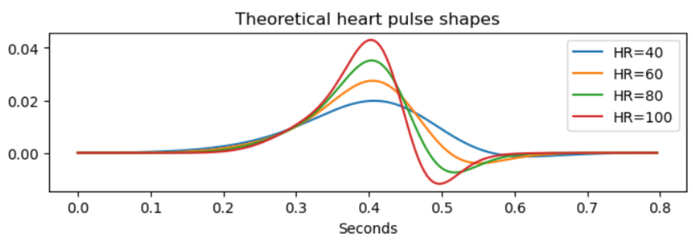
Data augmentation → Select multiple 15 second samples from 30 second clips

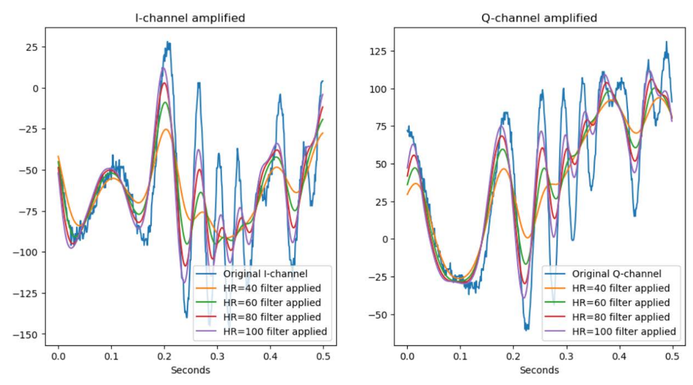
Radar data preprocessing → Select radar with highest signal variance, amplify heart pulse

Train, validate, test model → Design model architecture and evaluate its efficacy

Heart Pulse Amplification

- Device Realization Lab found that cross correlating a filter of **a theoretical heart pulse shape** to radar data significantly boosts strength of heart pulses
- We applied 4 filters (heart pulse shape of heart rate 40, 60, 80 & 100 BPM) to I & Q channels

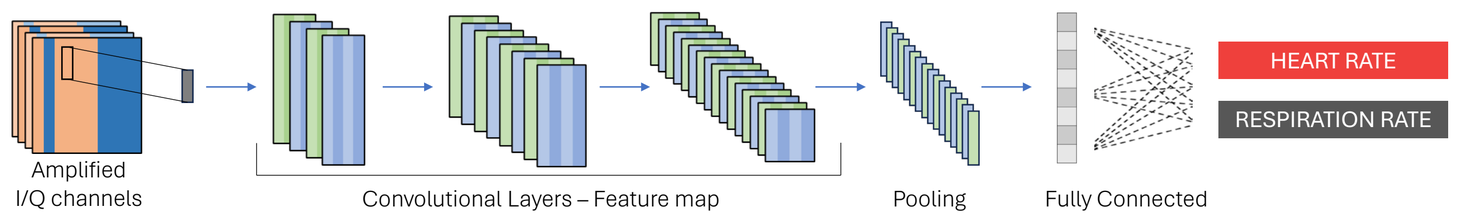




Model 1: ResNet-based architecture for predicting heart and respiration rate

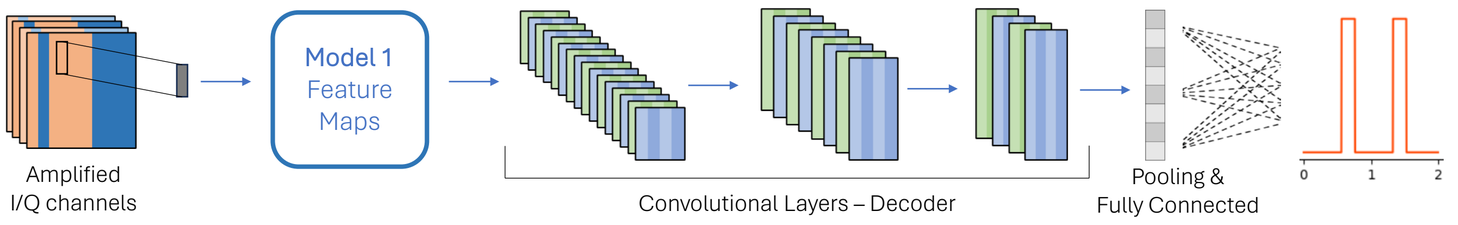
Drawing inspiration from **computer vision**, we based our final model on the famous computer vision model ResNet-18, with the following modifications:

- **Dimension Adaptation** Transformed model for 1D signals instead of 2D images
- **Depth Augmentation** Added 3 convolution layers to each block to a total of 5 per block
- **Filter Dilation** Enlarged filter sizes to capture extended waveforms
- **Channel Expansion** Doubled the max number of channels from 512 to 1024



Model 2: Encoder-decoder architecture for predicting timestamp of heart pulses

By adding decoding layers to Model 1, we predict for each 100 milliseconds in the input, whether the radar data contains the peaks of a heart pulse (1 if yes, 0 if no)



RESULT

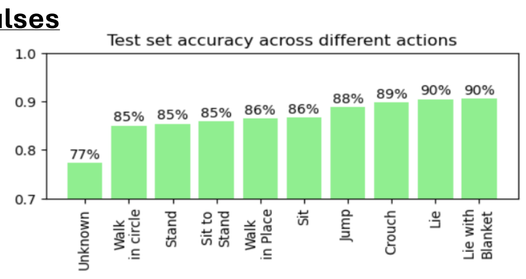
Model 1: Predicting heart and respiration rate

Dataset	MAE	MAE - HR	MAE - RR	R^2 - HR	R^2 - RR
Train set	2.43	1.48	0.95	0.97	0.89
Validation set	3.74	2.43	1.32	0.90	0.79
Test set	3.73	2.40	1.34	0.91	0.78

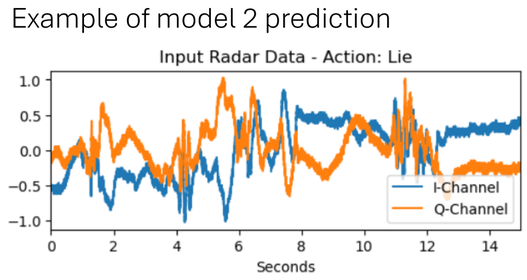
**MAE: mean absolute error; HR: heart rate; RR: respiration rate*

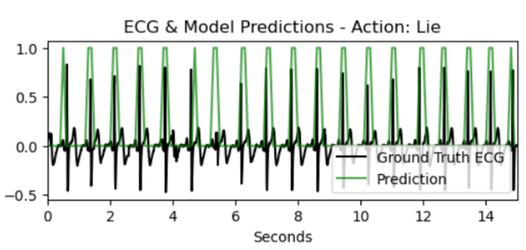
Model 2: Predicting timestamp of heart pulses

Dataset	Accuracy	F1 Score
Train set	99.99%	99.99%
Validation set	88.49%	73.85%
Test set	88.72%	74.26%



Example of model 2 prediction





DELIVERABLE & BUSINESS IMPACT

- Extensive Vital Signs Predictive Frameworks
  - **Deepened, Dilated ResNet-18 Model** for Heart and Respiration Rate Estimation
  - **Encoder-Decoder Model** for R-Peak Prediction
  - **Customizable Amplification Layers** for Radar Preprocess
- Potential for real-time non-intrusive health monitoring system
- Versatility across motion activities and real-world implication
- Addressing noise challenges and meaningful health metrics extraction

NEXT STEPS

Following our project, MIT Device Realization Lab will continue to validate, generalize and deploy our deliverables for Sekisui House. This includes:

- Combining heart rate and respiration rate with movement detection model
- Curating a dataset focused on irregular heart and respiration patterns
- Deployment into Sekisui House's eco-system with alarming features