QualityDeepSense: Quality-Aware Deep Learning Framework for Internet of Things Applications with Sensor-Temporal Attention

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DeepSense vs QualityDeepSense

- DeepSense
  - Unified neural network framework
  - Proved to be very good for mobile sensing and computing tasks
  - Does not consider noise/heterogenous qualily of the sensor data

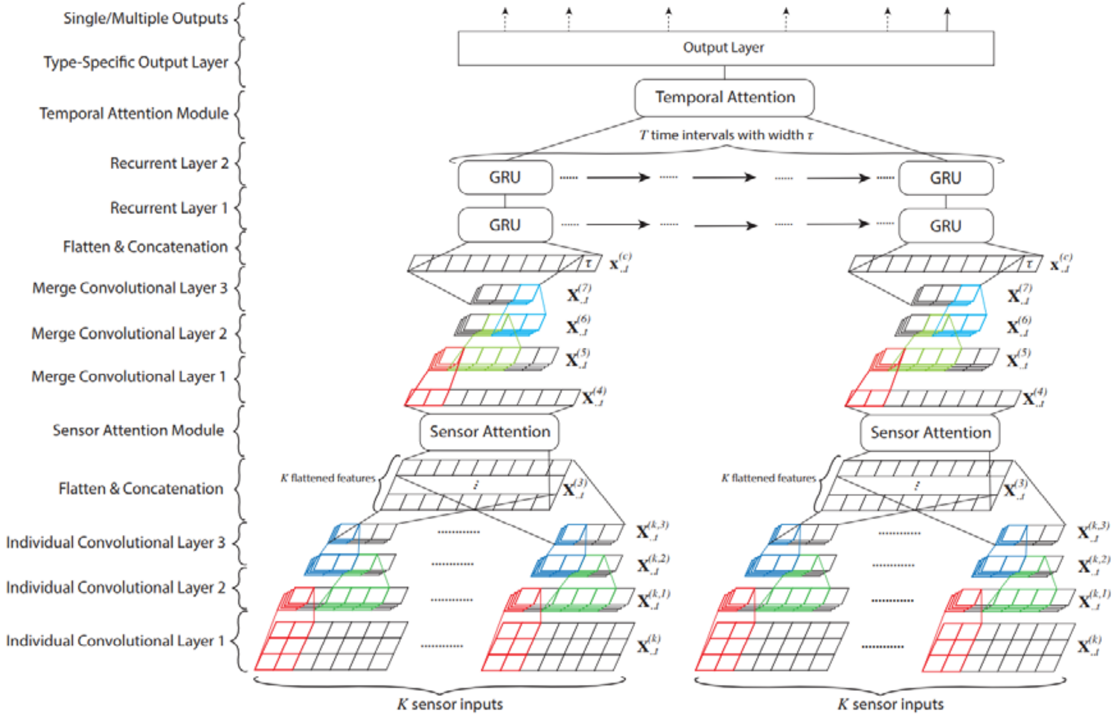
Solution!!

- QualityDeepSense
  - Modification of DeepSense to consider noise in the data
  - Uses sensor-temporal self-attention mechanism
  - Identify the qualities of input by calculating dependencies of their internal representation in DNN

Noise

- Low cost sensors
  - Insufficient accuracy, calibration & granularity
- Heavy multitasking & I/O workload
- May be due to other components of the system
- Noise do not determine the complex dependency between sensing inputs

Network Architecture



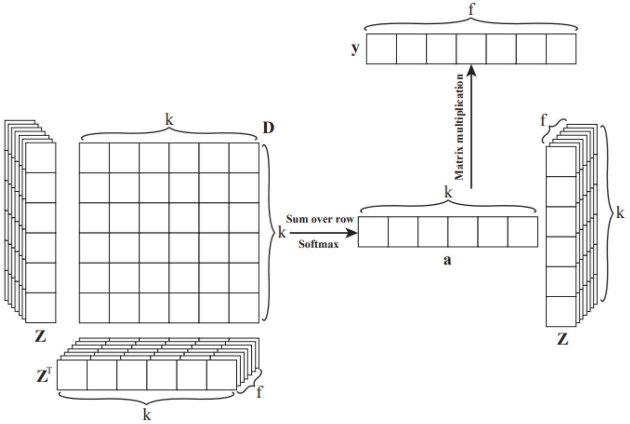
Data Flow

- Raw sensor data is divided across time for width t and a fourier transform is applied to each interval--Input of the network
- 3 Individual conv layers for extracting relations within a sensor
- Sensor Attention
- 3 Merge layers to extract relations between sensors
- RNN to extract temporal dependencies
- Temporal attention module
- Output (softmax)

Self-Attention

- Estimate sensing quality
  - Calculate internal dependencies
- Two steps
  - Calculate attention vector a $\mathbf{a} = \text{Softmax}\left(\mathbf{1} \cdot (\mathbf{Z} \cdot \mathbf{Z}^\top)\right)$
  - Weighted sum over rows using a

$$\mathbf{y} = \mathbf{a} \cdot \mathbf{Z}$$



- To determine the dependencies among k-vectors

Evaluation

- Nexus-5
  - 2.3GHz, 2GB memory, manually set to 1.1GHz
- TensorFlow-for-mobile
  - For DNN methods
  - Weka for SVM
- Dataset
  - 2-motion sensors-Accelerometer and gyroscope
  - 9 users with 6 activities (un-ordered)
  - Noise-augmented using white gaussian noise on either of time or frequency domain.

Accuracy Improvements

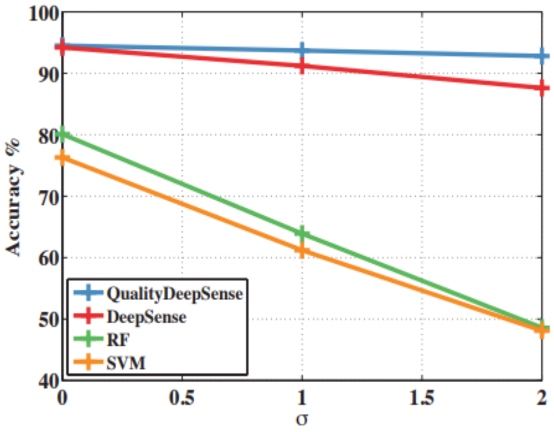


Figure 3: The accuracy of algorithms on HHAR with additive white Gaussian noise on frequency domain.

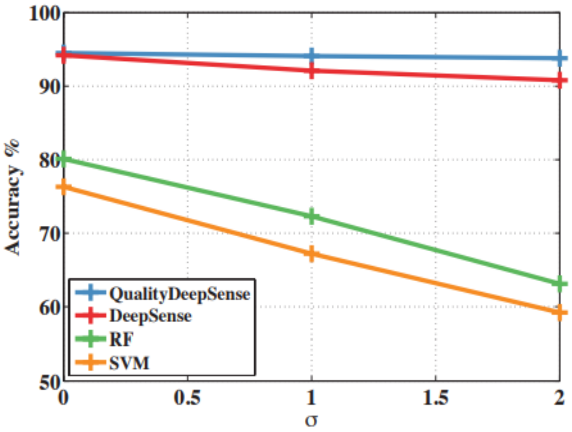


Figure 4: The accuracy of algorithms on HHAR with additive white Gaussian noise on time domain.

Effectiveness

- Attention
  - Multiplication of two attention modules
- Correlation b/w noise and Attention
  - Non-linear
  - Difference in sensing measurement
- Attention is small for strong noise

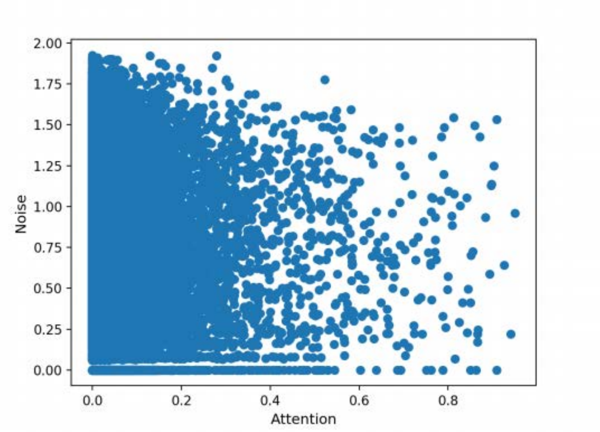


Figure 5: The correlation between attention and additive noise.

Execution time & Energy consumption

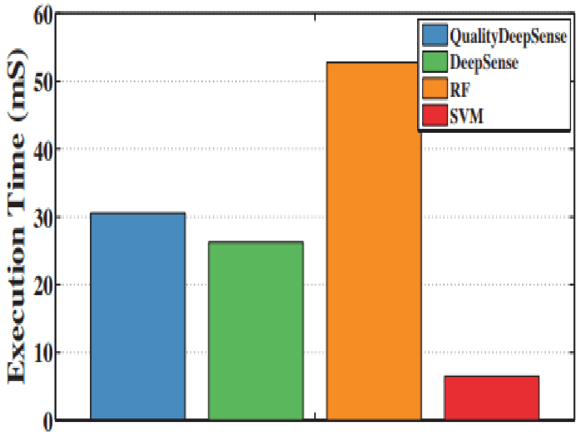


Figure 6: The execution time of algorithms on Nexus 5.

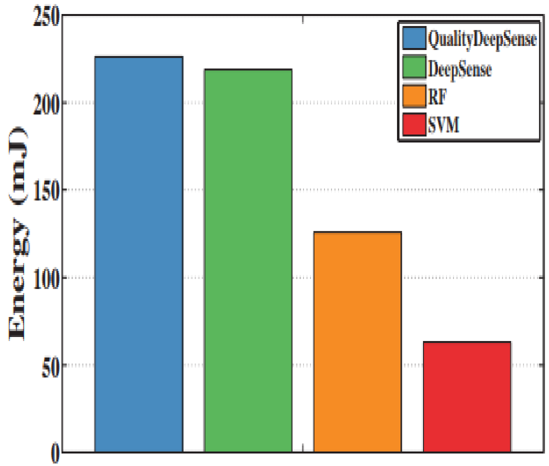


Figure 7: The energy consumption of algorithms on Nexus 5.

Overall

- QualityDeepSense performs better than DeepSense and is able to solve the heterogeneous quality sensing problem
- It shows lower performance degradation but with the expense of some execution time and energy consumption overhead
- There is no optimization done. Hyperparameter tuning & more network optimization can be done to reduce the overhead.