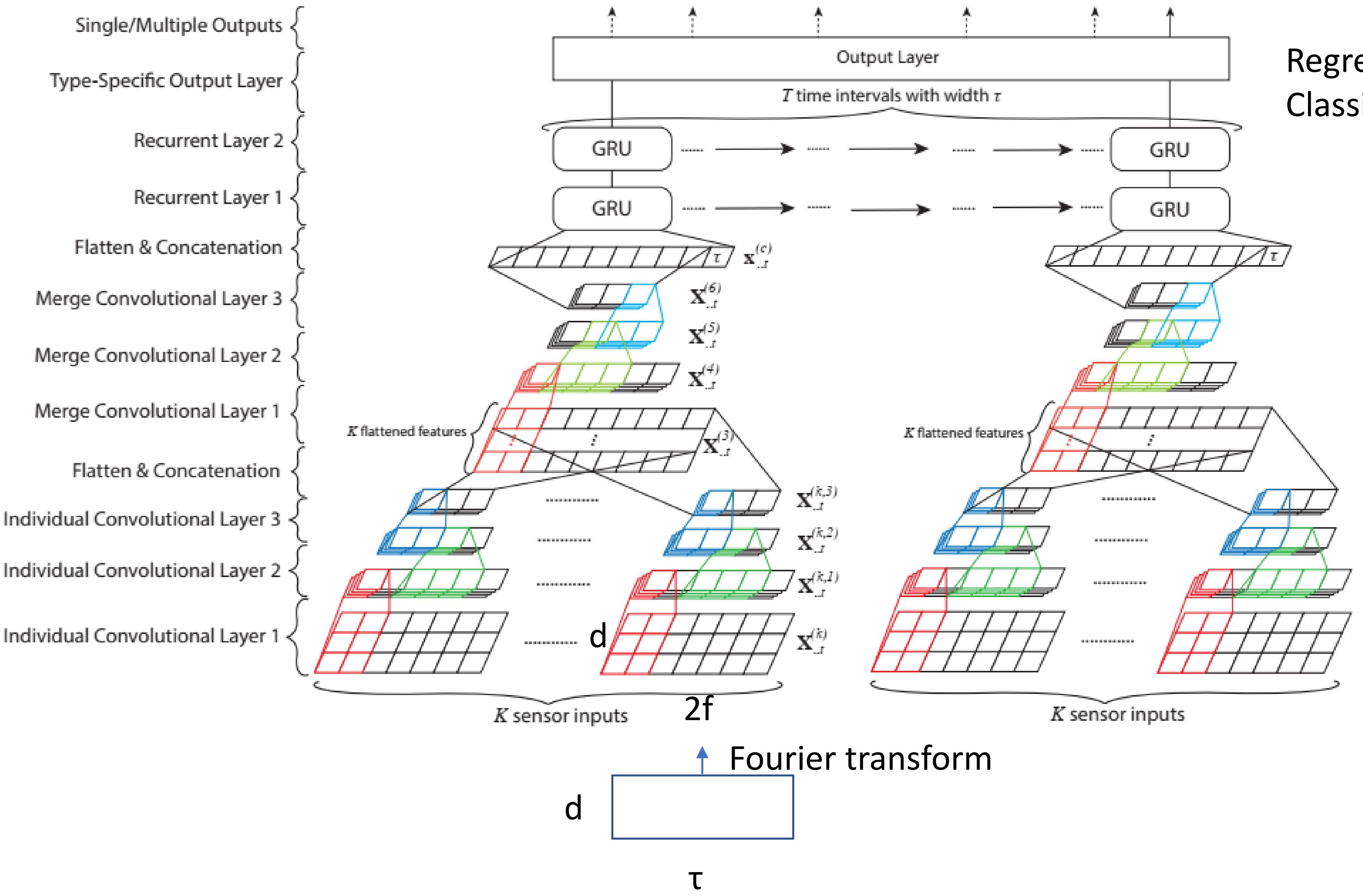
Deepsense: A unified deep learning framework for time-series mobile sensing data processing

Yao, Shuochao, et al. "Deepsense: A unified deep learning framework for time-series mobile sensing data processing." *Proceedings of the 26th International Conference on World Wide Web*. International World Wide Web Conferences Steering Committee, 2017.

Background

- Mobile sensing and computing applications
  - Accelerometers, gyroscopes, and magnetometers
  - Tracking, activity recognition
- Challenges
  - On-device sensor measurements are noisy
  - It is not always straightforward to find the most robust features
- Innovations:
  - Modeling temporal relationships
  - Fusing multimodal sensor inputs

DeepSense Framework



Regression: $\hat{\mathbf{y}}_t = \mathbf{W}_{out} \cdot \mathbf{x}_t^{(r)} + \mathbf{b}_{out}.$

Classification: $\mathbf{x}^{(r)} = (\sum_{t=1}^{T} \mathbf{x}_t^{(r)})/T.$

then softmax

Application- Car tracking with motion sensors (CarTrack)

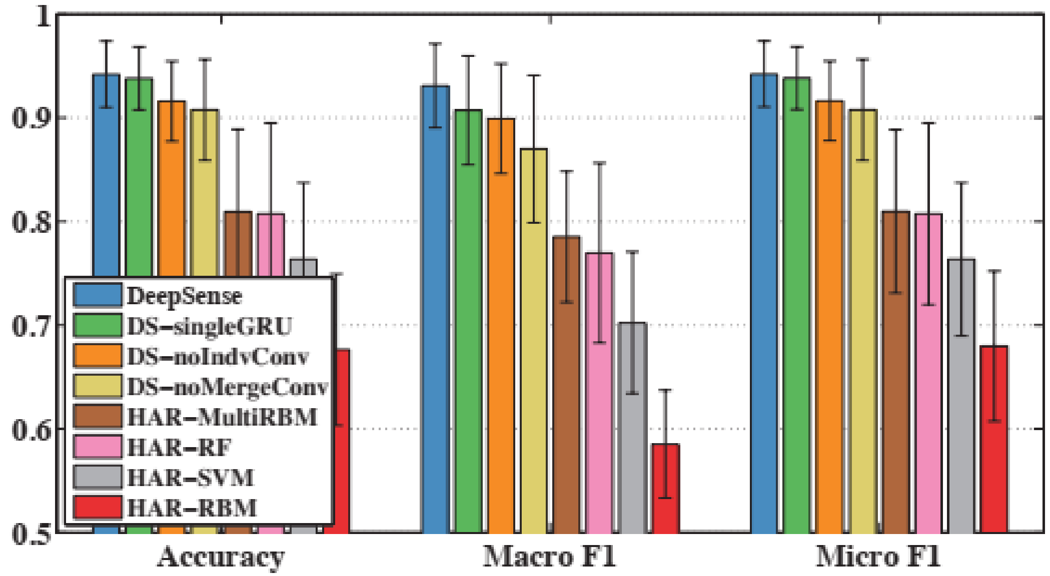
Measurement tools	accelerator, gyroscope, and magnetometer (K=3)
Data	approximately 1760 samples
Evaluation	253 samples to evaluate
Ground truth	GPS 2D displacement of the car
Loss function:	$\mathcal{L} = -\log\left(\mathbf{Y}_{[t]}\left(\mathcal{F}(\mathcal{X})_{[t]}\right)\right) + \sum_{t=1}^{T} \lambda \cdot \max\left(0, \cos(\theta) - S_c\left(\mathcal{F}(\mathcal{X})_{[t]}, \mathbf{y}^{(t)}\right)\right)$
Results:	

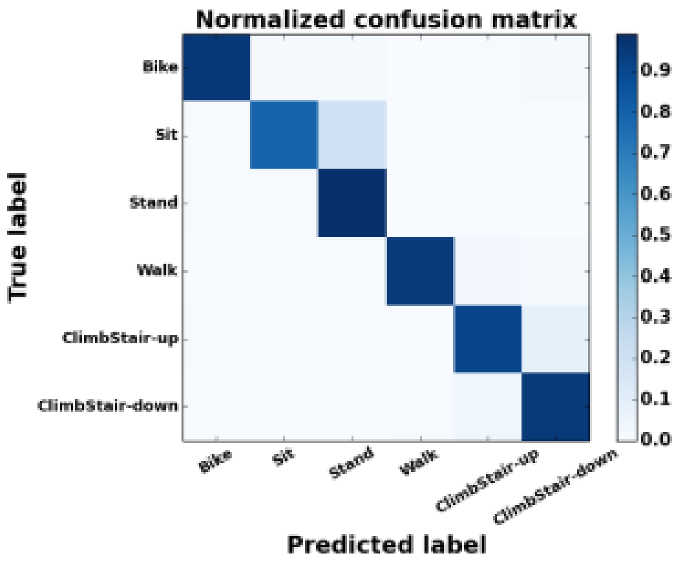
Table 1: CarTrack Task Accuracy

	MAE (meter)	Map-Aided Accuracy
DeepSense	$\mathbf{40.43 \pm 5.24}$	**93.8%**
DS-SingleGRU	44.97 ± 5.80	90.2%
DS-noIndvConv	52.15 ± 6.24	88.3%
DS-noMergeConv	53.06 ± 6.59	87.5%
Sensor-fusion	606.59 ± 56.57	
eNav (w/o GPS)		6.7%

Application-Heterogeneous Human activity recognition (HHAR)

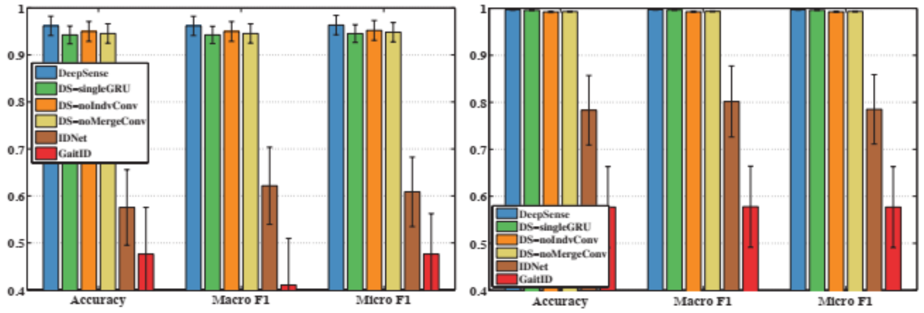
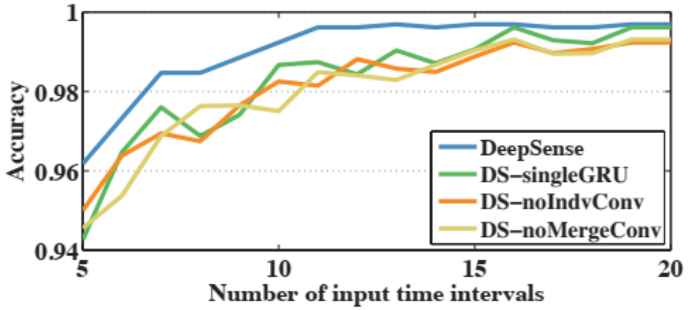
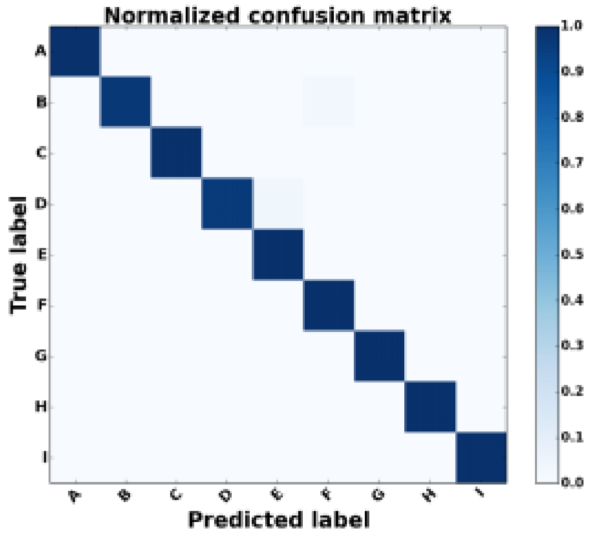
Measurement tools	accelerator, gyroscope (K=2);
Data	Allen et al. 2015, 9 users, **6 activities**, 5 mins, 6devices
Evaluation	Leave-one-subject-out cross-validation
Loss function:	Cross-entropy
Results:	





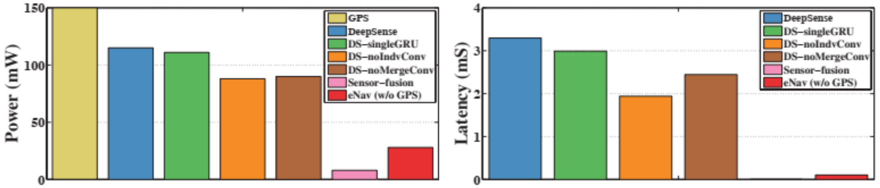
https://en.wikipedia.org/wiki/F1_score

Application-User Identification with motion analysis (UserID)

Measurement tools	accelerator, gyroscope (K=2);
Data	Allen et al. 2015, 9 users, **6 activities**, 5 mins, 6devices
Evaluation	10-fold
Loss function:	Cross-entropy
Results:	 (a) 5 time intervals: 1.25s (b) 20 time intervals: 5s Figure 7: Performance metrics of UserID task.  

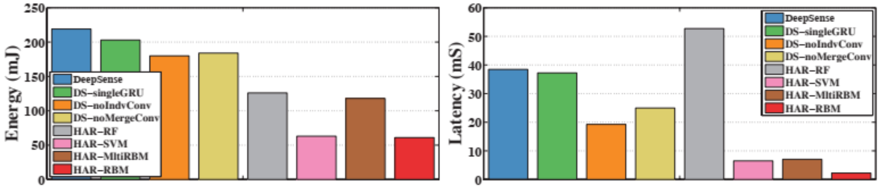
Latency and Energy

Figure 9: Test Platforms: Nexus5 and Intel Edison.



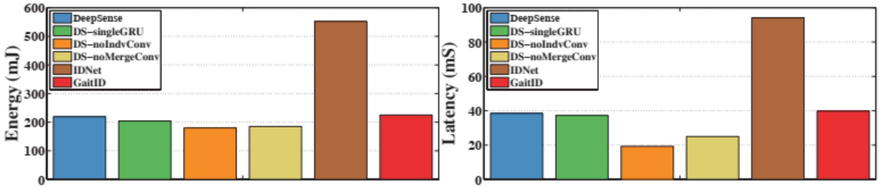
(a) Power (b) Latency

Figure 10: Power and Latency of carTrack solutions on Nexus 5



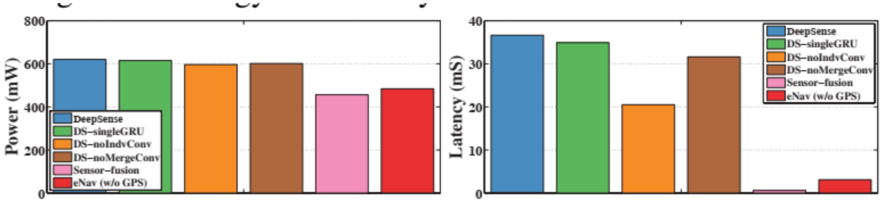
(a) Energy (b) Latency

Figure 11: Energy and Latency of HHAR solutions on Nexus 5



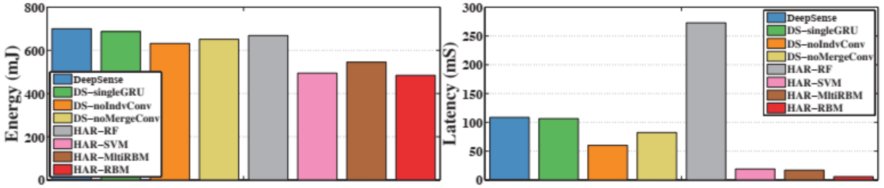
(a) Energy (b) Latency

Figure 12: Energy and Latency of UserID solutions on Nexus 5



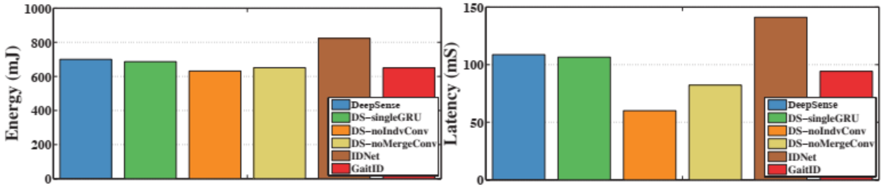
(a) Power (b) Latency

Figure 13: Power and Latency of carTrack solutions on Intel Edison



(a) Energy (b) Latency

Figure 14: Energy and Latency of HHAR solutions on Intel Edison



(a) Energy (b) Latency

Figure 15: Energy and Latency of UserID solutions on Intel Edison