Light Residual Network for Human Activity Recognition using Wearable Sensor Data

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Index Terms—deep learning, human activity recognition, residual network, inertial sensors

APPENDIX: ABLATION STUDY

Here we present additional results on the ablation study intended to find the optimal number of residual blocks for our model. This information extends the experimental results of the original paper. The labels of the activities are:

- WA: Walking
- WU: Walking Upstairs
- WD: Walking Downstairs
- SI: Sitting
- ST: Standing
- LA: Laying

The tables in this appendix show the results in terms of 4 metrics:

- Precision (P): It is defined as the number of true positives (T_p) over the sum of true positives and false positives (F_p)

$$P = \frac{T_p}{T_p + F_p} \tag{1}$$

- Recall (R): It is defined as the number of true positives (T_p) over the sum of true positive and false negatives (F_n)

$$R = \frac{T_p}{T_p + F_n} \tag{2}$$

- F1-Score: It is defined as the harmonic mean of precision and recall.

$$F1 - score = 2 \cdot \frac{P \cdot R}{P + R} \tag{3}$$

- F1-Score Average: It is the average of the F1-scores of all the classes.

$$F1 - score_{avg} = \frac{1}{N} \sum_{i=1}^{N} F1 - score_i \tag{4}$$

  Where N is the number of classes.

- F1-Score Weighted: It is defined as the average of F1-scores of all the classes weighted by the number of instances in each class.

$$F1 - score_{\text{Weighted}} = \frac{1}{\sum_{i=1}^{N} w_i} \sum_{i=1}^{N} w_i \cdot F1 - score_i \tag{5}$$

  Where w_i is the number of instances in the ith class and N the number of classes.

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TABLE 1. Ablation study data

Number of Residual Blocks	F1-Score Average	Parameters
6	95.6	959174
5	96.4	564934
4	**97.6**	**234950**
3	96.2	136134
2	94.6	53062
1	94.9	28230
0	94.1	3398

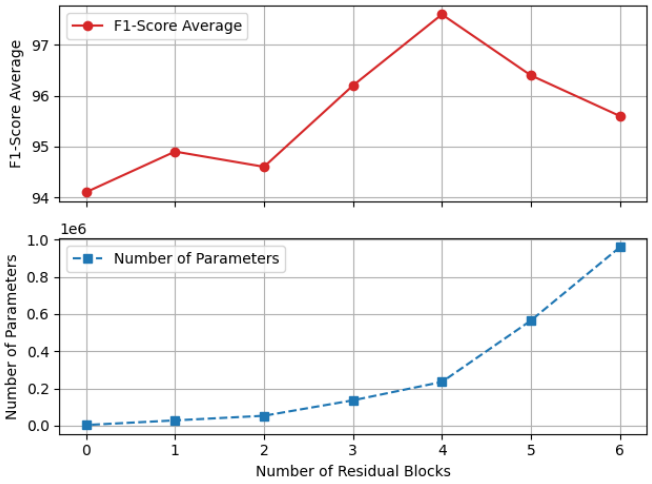

Fig. 1. Average of F1 score along the 6 classes and number of parameters depending on the number of residual blocks

TABLE 2. Model with 6 Residual Blocks

Classes	Precision	Recall	F1-Score	Support
WA	1.000	0.942	0.970	496
WU	0.996	0.949	0.972	471
WD	0.890	1.000	0.942	420
SI	0.973	0.868	0.917	491
ST	0.900	0.979	0.938	532
LA	0.991	1.000	0.995	537

TABLE 3. Model with 5 Residual Blocks

Classes	Precision	Recall	F1-Score	Support
WA	1.000	0.948	0.973	496
WU	1.000	0.951	0.975	471
WD	0.896	1.000	0.945	420
SI	0.972	0.914	0.942	491
ST	0.935	0.976	0.955	532
LA	0.989	1.000	0.994	537

TABLE 4. Model with 4 Residual Blocks

Classes	Precision	Recall	F1-Score	Support
WA	1.000	0.962	0.980	496
WU	0.985	0.998	0.992	471
WD	0.961	0.995	0.978	420
SI	0.983	0.916	0.948	491
ST	0.939	0.985	0.961	532
LA	0.991	1.000	0.995	537

TABLE 5. Model with 3 Residual Blocks

Classes	Precision	Recall	F1-Score	Support
WA	0.998	0.966	0.982	496
WU	0.985	0.968	0.976	471
WD	0.972	1.000	0.986	420
SI	0.934	0.864	0.897	491
ST	0.899	0.974	0.935	532
LA	0.991	1.000	0.995	537

TABLE 6. Model with 2 Residual Blocks

Classes	Precision	Recall	F1-Score	Support
WA	0.994	0.950	0.971	496
WU	0.989	0.970	0.980	471
WD	0.965	0.988	0.976	420
SI	0.900	0.802	0.848	491
ST	0.851	0.966	0.905	532
LA	0.996	1.000	0.998	537

TABLE 7. Model with 1 Residual Blocks

Classes	Precision	Recall	F1-Score	Support
WA	1.000	0.998	0.999	496
WU	0.991	0.958	0.974	471
WD	0.998	1.000	0.999	420
SI	0.860	0.866	0.863	491
ST	0.856	0.906	0.880	532
LA	0.996	0.963	0.979	537

TABLE 8. Model with 0 Residual Blocks

Classes	Precision	Recall	F1-Score	Support
WA	0.988	1.000	0.994	496
WU	0.987	0.947	0.966	471
WD	0.950	0.995	0.972	420
SI	0.856	0.837	0.847	491
ST	0.868	0.868	0.868	532
LA	0.993	1.000	0.996	537

TABLE 9. Ablation Study: Accuracy, F1-Score Average, F1-Score Weighted, and support.

Residual Blocks	Accuracy	F1-Score Average	F1-Score Weighted
6	0.956	0.956	0.956
5	0.965	0.964	0.965
4	0.976	0.976	0.976
3	0.962	0.962	0.961
2	0.946	0.946	0.946
1	0.947	0.949	0.947
0	0.940	0.941	0.940

TABLE 10. Summary table of the ablation study with the average values over the 6 classes. We display the results in the format: $\mu \pm std$, where μ is the average value and std is the standard deviation. The Residual Blocks column refers to the number of residual blocks of each model.

Residual Blocks	Precision	Recall	F1-Score
6	0.958 ± 0.050	0.956 ± 0.050	0.956 ± 0.028
5	0.965 ± 0.042	0.965 ± 0.033	0.964 ± 0.020
4	0.976 ± 0.022	0.976 ± 0.032	0.976 ± 0.018
3	0.963 ± 0.039	0.962 ± 0.051	0.962 ± 0.038
2	0.949 ± 0.060	0.946 ± 0.073	0.946 ± 0.058
1	0.950 ± 0.071	0.948 ± 0.053	0.949 ± 0.061
0	0.940 ± 0.062	0.941 ± 0.072	0.941 ± 0.066

TABLE 11. Confusion matrix from the model with 6 residual blocks.

		Predicted label						
		WA	WU	WD	SI	ST	LA	Sup.
Actual label	WA	**94.2%**	0.0%	5.6%	0.2%	0.0%	0.0%	
		467	0	28	1	0	0	496
	WU	0.0%	**94.9%**	5.1%	0.0%	0.0%	0.0%	
		0	**447**	24	0	0	0	471
	WD	0.0%	0.0%	**100.0%**	0.0%	0.0%	0.0%	
		0	0	**420**	0	0	0	420
	SI	0.0%	0.4%	0.0%	**86.8%**	11.8%	1.0%	
		0	2	0	**426**	58	5	491
	ST	0.0%	0.0%	0.0%	2.1%	**97.9%**	0.0%	
		0	0	0	11	**521**	0	532
	LA	0.0%	0.0%	0.0%	0.0%	0.0%	**100.0%**	
		0	0	0	0	0	**537**	537

TABLE 12. Confusion matrix from the model with 5 residual blocks.

		Predicted label						
		WA	WU	WD	SI	ST	LA	Sup.
Actual label	WA	**94.8%**	0.0%	5.2%	0.0%	0.0%	0.0%	
		470	0	26	0	0	0	496
	WU	0.0%	**95.1%**	4.9%	0.0%	0.0%	0.0%	
		0	**448**	23	0	0	0	471
	WD	0.0%	0.0%	**100.0%**	0.0%	0.0%	0.0%	
		0	0	**420**	0	0	0	420
	SI	0.0%	0.0%	0.0%	**91.4%**	7.3%	1.2%	
		0	0	0	**449**	36	6	491
	ST	0.0%	0.0%	0.0%	2.4%	**97.6%**	0.0%	
		0	0	0	13	**519**	0	532
	LA	0.0%	0.0%	0.0%	0.0%	0.0%	**100.0%**	
		0	0	0	0	0	**537**	537

TABLE 13. Confusion matrix from the model with 4 residual blocks.

		Predicted label						
		WA	WU	WD	SI	ST	LA	Sup.
Actual label	WA	**96.2%**	0.6%	3.2%	0.0%	0.0%	0.0%	
		477	3	16	0	0	0	496
	WU	0.0%	**99.8%**	0.2%	0.0%	0.0%	0.0%	
		0	**470**	1	0	0	0	471
	WD	0.0%	0.5%	**99.5%**	0.0%	0.0%	0.0%	
		0	2	**418**	0	0	0	420
	SI	0.0%	0.4%	0.0%	**91.6%**	6.9%	1.0%	
		0	2	0	**450**	34	5	491
	ST	0.0%	0.0%	0.0%	1.5%	**98.5%**	0.0%	
		0	0	0	8	**524**	0	532
	LA	0.0%	0.0%	0.0%	0.0%	0.0%	**100.0%**	
		0	0	0	0	0	**537**	537

TABLE 14. Confusion matrix from the model with 3 residual blocks.

Actual label \ Predicted label	WA	WU	WD	SI	ST	LA	Sup.
WA	**96.6%**	0.6%	1.8%	1.0%	0.0%	0.0%	
	479	3	9	5	0	0	496
WU	0.2%	**96.8%**	0.6%	2.3%	0.0%	0.0%	
	1	**456**	3	11	0	0	471
WD	0.0%	0.0%	**100.0%**	0.0%	0.0%	0.0%	
	0	0	**420**	0	0	0	420
SI	0.0%	0.8%	0.0%	**86.4%**	11.8%	1.0%	
	0	4	0	**424**	58	5	491
ST	0.0%	0.0%	0.0%	2.6%	**97.4%**	0.0%	
	0	0	0	14	**518**	0	532
LA	0.0%	0.0%	0.0%	0.0%	0.0%	**100.0%**	
	0	0	0	0	0	**537**	537

TABLE 15. Confusion matrix from the model with 2 residual blocks.

Actual label \ Predicted label	WA	WU	WD	SI	ST	LA	Sup.
WA	**95.0%**	0.0%	1.8%	3.2%	0.0%	0.0%	
	471	0	9	16	0	0	496
WU	0.6%	**97.0%**	1.3%	1.1%	0.0%	0.0%	
	3	**457**	6	5	0	0	471
WD	0.0%	0.0%	**98.8%**	1.2%	0.0%	0.0%	
	0	0	**415**	5	0	0	420
SI	0.0%	1.0%	0.0%	**80.2%**	18.3%	0.4%	
	0	5	0	**394**	90	2	491
ST	0.0%	0.0%	0.0%	3.4%	**96.6%**	0.0%	
	0	0	0	18	**514**	0	532
LA	0.0%	0.0%	0.0%	0.0%	0.0%	**100.0%**	
	0	0	0	0	0	**537**	537

TABLE 16. Confusion matrix from the model with 1 residual block.

Actual label \ Predicted label	WA	WU	WD	SI	ST	LA	Sup.
WA	**99.8%**	0.2%	0.0%	0.0%	0.0%	0.0%	
	495	1	0	0	0	0	496
WU	0.0%	**95.8%**	0.2%	4.0%	0.0%	0.0%	
	0	**451**	1	19	0	0	471
WD	0.0%	0.0%	**100.0%**	0.0%	0.0%	0.0%	
	0	0	**420**	0	0	0	420
SI	0.0%	0.6%	0.0%	**86.6%**	12.4%	0.4%	
	0	3	0	**425**	61	2	491
ST	0.0%	0.0%	0.0%	9.4%	**90.6%**	0.0%	
	0	0	0	50	**482**	0	532
LA	0.0%	0.0%	0.0%	0.0%	3.7%	**96.3%**	
	0	0	0	0	20	**517**	537

TABLE 17. Confusion matrix from the model with 0 residual block.

Actual label \ Predicted label	WA	WU	WD	SI	ST	LA	Sup.
WA	**100.0%**	0.0%	0.0%	0.0%	0.0%	0.0%	
	496	0	0	0	0	0	496
WU	0.6%	**94.7%**	4.7%	0.0%	0.0%	0.0%	
	3	**446**	22	0	0	0	471
WD	0.5%	0.0%	**99.5%**	0.0%	0.0%	0.0%	
	2	0	**418**	0	0	0	420
SI	0.0%	1.2%	0.0%	**83.7%**	14.3%	0.8%	
	0	6	0	**411**	70	4	491
ST	0.2%	0.0%	0.0%	13.0%	**86.8%**	0.0%	
	1	0	0	69	**462**	0	532
LA	0.0%	0.0%	0.0%	0.0%	0.0%	**100.0%**	
	0	0	0	0	0	**537**	537