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: 10-FOLD CROSS-VALIDATION

This appendix presents results on the 10-fold cross-validation study. Each fold contains 3 participants. The participants in the test sets are different from the participants in the training sets. 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 (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 Macro: It is the average of the F1-scores of all the classes.

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

  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. 10 fold Cross-Validation: Fold 1

Classes	Precision	Recall	F1-Score	Support
WA	1.000	1.000	1.000	212
WU	0.994	0.994	0.994	160
WD	1.000	1.000	1.000	145
SI	0.993	0.945	0.968	145
ST	0.954	0.994	0.974	168
LA	1.000	1.000	1.000	160

TABLE 2. 10 fold Cross-Validation: Fold 2

Classes	Precision	Recall	F1-Score	Support
WA	1.000	1.000	1.000	173
WU	1.000	1.000	1.000	150
WD	1.000	1.000	1.000	140
SI	0.819	0.940	0.875	149
ST	0.939	0.817	0.873	169
LA	1.000	1.000	1.000	163

TABLE 3. 10 fold Cross-Validation: Fold 3

Classes	Precision	Recall	F1-Score	Support
WA	1.000	1.000	1.000	157
WU	0.979	1.000	0.989	141
WD	1.000	1.000	1.000	127
SI	0.918	0.938	0.928	144
ST	0.966	0.921	0.943	152
LA	0.994	1.000	0.997	156

TABLE 4. 10 fold Cross-Validation: Fold 4

Classes	Precision	Recall	F1-Score	Support
WA	1.000	0.883	0.938	162
WU	1.000	0.843	0.915	153
WD	0.751	1.000	0.858	130
SI	0.979	0.899	0.937	158
ST	0.903	0.980	0.940	152
LA	1.000	1.000	1.000	175

TABLE 5. 10 fold Cross-Validation: Fold 5

Classes	Precision	Recall	F1-Score	Support
WA	1.000	0.653	0.790	170
WU	0.727	1.000	0.842	157
WD	1.000	1.000	1.000	134
SI	0.981	0.975	0.978	162
ST	0.977	0.982	0.979	170
LA	1.000	1.000	1.000	185

TABLE 6. 10 fold Cross-Validation: Fold 6

Classes	Precision	Recall	F1-Score	Support
WA	1.000	1.000	1.000	168
WU	1.000	1.000	1.000	157
WD	1.000	1.000	1.000	148
SI	0.822	0.921	0.868	190
ST	0.927	0.834	0.878	229
LA	1.000	1.000	1.000	206

TABLE 7. 10 fold Cross-Validation: Fold 7

Classes	Precision	Recall	F1-Score	Support
WA	1.000	1.000	1.000	155
WU	1.000	1.000	1.000	138
WD	1.000	1.000	1.000	129
SI	1.000	0.929	0.963	224
ST	0.948	1.000	0.973	235
LA	0.988	1.000	0.994	241

TABLE 8. 10 fold Cross-Validation: Fold 8

Classes	Precision	Recall	F1-Score	Support
WA	1.000	1.000	1.000	163
WU	1.000	1.000	1.000	152
WD	1.000	0.993	0.997	145
SI	0.956	0.995	0.975	198
ST	0.990	0.955	0.972	200
LA	1.000	1.000	1.000	216

TABLE 9. 10 fold Cross-Validation: Fold 9

Classes	Precision	Recall	F1-Score	Support
WA	1.000	1.000	1.000	190
WU	1.000	1.000	1.000	171
WD	1.000	1.000	1.000	152
SI	0.921	0.986	0.952	213
ST	0.986	0.921	0.952	228
LA	1.000	1.000	1.000	223

TABLE 10. 10 fold Cross-Validation: Fold 10

Classes	Precision	Recall	F1-Score	Support
WA	1.000	0.994	0.997	172
WU	0.994	1.000	0.997	165
WD	1.000	1.000	1.000	156
SI	0.955	0.871	0.911	194
ST	0.886	0.961	0.922	203
LA	1.000	1.000	1.000	219

TABLE 11. 10 Fold Cross-Validation: Accuracy, F1-Score Macro, F1-Score Weighted, and support.

Fold	Accuracy	F1-Score Macro	F1-Score Weighted	Support
1	0.990	0.989	0.990	990
2	0.958	0.958	0.958	944
3	0.976	0.976	0.976	877
4	0.933	0.931	0.935	930
5	0.933	0.932	0.931	978
6	0.952	0.958	0.952	1098
7	0.986	0.988	0.986	1122
8	0.990	0.991	0.990	1074
9	0.982	0.984	0.982	1177
10	0.969	0.971	0.969	1109

TABLE 12. Summary table of 10-fold cross-validation with average values over the classes. We display the results in the format: $\mu \pm std$, where μ is the average value and std is the standard deviation. Participant ID refers to the ID of the participant belonging to the test set in each fold. *The average F1-score over the classes has been defined as F1-Score Macro in the equation 4, however, we do not use the term F1-Score Macro as the table heading because we also show the standard deviation.

Fold	Precision	Recall	F1-Score*	Participant ID
1	0.990 ± 0.018	0.989 ± 0.022	0.989 ± 0.014	1,2,3
2	0.960 ± 0.073	0.959 ± 0.074	0.958 ± 0.065	4,5,6
3	0.976 ± 0.031	0.976 ± 0.037	0.976 ± 0.032	7,8,9
4	0.939 ± 0.099	0.934 ± 0.068	0.931 ± 0.046	10,11,12
5	0.947 ± 0.109	0.935 ± 0.139	0.932 ± 0.092	13,14,15
6	0.958 ± 0.073	0.959 ± 0.069	0.958 ± 0.065	16,17,18
7	0.989 ± 0.021	0.988 ± 0.029	0.988 ± 0.016	19,20,21
8	0.991 ± 0.017	0.991 ± 0.018	0.991 ± 0.013	22,23,24
9	0.984 ± 0.032	0.984 ± 0.032	0.984 ± 0.025	25,26,27
10	0.973 ± 0.046	0.971 ± 0.051	0.971 ± 0.043	28,29,30

TABLE 13. Confusion matrix fold 1

		Predicted label						
		WA	WU	WD	SI	ST	LA	Sup.
Actual label	WA	**100.0%**	0.0%	0.0%	0.0%	0.0%	0.0%	
		212	0	0	0	0	0	212
	WU	0.0%	**99.4%**	0.0%	0.0%	0.6%	0.0%	
		0	**159**	0	0	1	0	160
	WD	0.0%	0.0%	**100.0%**	0.0%	0.0%	0.0%	
		0	0	**145**	0	0	0	145
	SI	0.0%	0.7%	0.0%	**94.5%**	4.8%	0.0%	
		0	1	0	**137**	7	0	145
	ST	0.0%	0.0%	0.0%	0.6%	**99.4%**	0.0%	
		0	0	0	1	**167**	0	168
	LA	0.0%	0.0%	0.0%	0.0%	0.0%	**100.0%**	
		0	0	0	0	0	**160**	160

TABLE 14. Confusion matrix fold 2

		Predicted label						
		WA	WU	WD	SI	ST	LA	Sup.
Actual label	WA	**100.0%**	0.0%	0.0%	0.0%	0.0%	0.0%	
		173	0	0	0	0	0	173
	WU	0.0%	**100.0%**	0.0%	0.0%	0.0%	0.0%	
		0	**150**	0	0	0	0	150
	WD	0.0%	0.0%	**100.0%**	0.0%	0.0%	0.0%	
		0	0	**140**	0	0	0	140
	SI	0.0%	0.0%	0.0%	**94.0%**	6.0%	0.0%	
		0	0	0	**140**	9	0	149
	ST	0.0%	0.0%	0.0%	18.3%	**81.7%**	0.0%	
		0	0	0	31	**138**	0	169
	LA	0.0%	0.0%	0.0%	0.0%	0.0%	**100.0%**	
		0	0	0	0	0	**163**	163

TABLE 15. Confusion matrix fold 3

		Predicted label						
		WA	WU	WD	SI	ST	LA	Sup.
Actual label	WA	**100.0%**	0.0%	0.0%	0.0%	0.0%	0.0%	
		157	0	0	0	0	0	157
	WU	0.0%	**100.0%**	0.0%	0.0%	0.0%	0.0%	
		0	**141**	0	0	0	0	141
	WD	0.0%	0.0%	**100.0%**	0.0%	0.0%	0.0%	
		0	0	**127**	0	0	0	127
	SI	0.0%	2.1%	0.0%	**93.8%**	3.5%	0.7%	
		0	3	0	**135**	5	1	144
	ST	0.0%	0.0%	0.0%	7.9%	**92.1%**	0.0%	
		0	0	0	12	**140**	0	152
	LA	0.0%	0.0%	0.0%	0.0%	0.0%	**100.0%**	
		0	0	0	0	0	**156**	156

TABLE 16. Confusion matrix fold 4

Actual label \ Predicted label	WA	WU	WD	SI	ST	LA	Sup.
WA	**88.3%**	0.0%	11.7%	0.0%	0.0%	0.0%	
	143	0	19	0	0	0	162
WU	0.0%	**84.3%**	15.7%	0.0%	0.0%	0.0%	
	0	**129**	24	0	0	0	153
WD	0.0%	0.0%	**100.0%**	0.0%	0.0%	0.0%	
	0	0	**130**	0	0	0	130
SI	0.0%	0.0%	0.0%	**89.9%**	10.1%	0.0%	
	0	0	0	**142**	16	0	158
ST	0.0%	0.0%	0.0%	2.0%	**98.0%**	0.0%	
	0	0	0	3	**149**	0	152
LA	0.0%	0.0%	0.0%	0.0%	0.0%	**100.0%**	
	0	0	0	0	0	**175**	175

TABLE 17. Confusion matrix fold 5

Actual label \ Predicted label	WA	WU	WD	SI	ST	LA	Sup.
WA	**65.3%**	34.7%	0.0%	0.0%	0.0%	0.0%	
	111	59	0	0	0	0	170
WU	0.0%	**100.0%**	0.0%	0.0%	0.0%	0.0%	
	0	**157**	0	0	0	0	157
WD	0.0%	0.0%	**100.0%**	0.0%	0.0%	0.0%	
	0	0	**134**	0	0	0	134
SI	0.0%	0.0%	0.0%	**97.5%**	2.5%	0.0%	
	0	0	0	**158**	4	0	162
ST	0.0%	0.0%	0.0%	1.8%	**98.2%**	0.0%	
	0	0	0	3	**167**	0	170
LA	0.0%	0.0%	0.0%	0.0%	0.0%	**100.0%**	
	0	0	0	0	0	**185**	185

TABLE 18. Confusion matrix fold 6

Actual label \ Predicted label	WA	WU	WD	SI	ST	LA	Sup.
WA	**100.0%**	0.0%	0.0%	0.0%	0.0%	0.0%	
	168	0	0	0	0	0	168
WU	0.0%	**100.0%**	0.0%	0.0%	0.0%	0.0%	
	0	**157**	0	0	0	0	157
WD	0.0%	0.0%	**100.0%**	0.0%	0.0%	0.0%	
	0	0	**148**	0	0	0	148
SI	0.0%	0.0%	0.0%	**92.1%**	7.9%	0.0%	
	0	0	0	**175**	15	0	190
ST	0.0%	0.0%	0.0%	16.6%	**83.4%**	0.0%	
	0	0	0	38	**191**	0	229
LA	0.0%	0.0%	0.0%	0.0%	0.0%	**100.0%**	
	0	0	0	0	0	**206**	206

TABLE 19. Confusion matrix fold 7

Actual label \ Predicted label	WA	WU	WD	SI	ST	LA	Sup.
WA	**100.0%**	0.0%	0.0%	0.0%	0.0%	0.0%	
	155	0	0	0	0	0	155
WU	0.0%	**100.0%**	0.0%	0.0%	0.0%	0.0%	
	0	**138**	0	0	0	0	138
WD	0.0%	0.0%	**100.0%**	0.0%	0.0%	0.0%	
	0	0	**129**	0	0	0	129
SI	0.0%	0.0%	0.0%	**92.9%**	5.8%	1.3%	
	0	0	0	**208**	13	3	224
ST	0.0%	0.0%	0.0%	0.0%	**100.0%**	0.0%	
	0	0	0	0	**235**	0	235
LA	0.0%	0.0%	0.0%	0.0%	0.0%	**100.0%**	
	0	0	0	0	0	**241**	241

TABLE 20. Confusion matrix fold 8

Actual label \ Predicted label	WA	WU	WD	SI	ST	LA	Sup.
WA	**100.0%**	0.0%	0.0%	0.0%	0.0%	0.0%	
	163	0	0	0	0	0	163
WU	0.0%	**100.0%**	0.0%	0.0%	0.0%	0.0%	
	0	**152**	0	0	0	0	152
WD	0.0%	0.0%	**99.3%**	0.0%	0.7%	0.0%	
	0	0	**144**	0	1	0	145
SI	0.0%	0.0%	0.0%	**99.5%**	0.5%	0.0%	
	0	0	0	**197**	1	0	198
ST	0.0%	0.0%	0.0%	4.5%	**95.5%**	0.0%	
	0	0	0	9	**191**	0	200
LA	0.0%	0.0%	0.0%	0.0%	0.0%	**100.0%**	
	0	0	0	0	0	**216**	216

TABLE 21. Confusion matrix fold 9

Actual label \ Predicted label	WA	WU	WD	SI	ST	LA	Sup.
WA	**100.0%**	0.0%	0.0%	0.0%	0.0%	0.0%	
	190	0	0	0	0	0	190
WU	0.0%	**100.0%**	0.0%	0.0%	0.0%	0.0%	
	0	**171**	0	0	0	0	171
WD	0.0%	0.0%	**100.0%**	0.0%	0.0%	0.0%	
	0	0	**152**	0	0	0	152
SI	0.0%	0.0%	0.0%	**98.6%**	1.4%	0.0%	
	0	0	0	**210**	3	0	213
ST	0.0%	0.0%	0.0%	7.9%	**92.1%**	0.0%	
	0	0	0	18	**210**	0	228
LA	0.0%	0.0%	0.0%	0.0%	0.0%	**100.0%**	
	0	0	0	0	0	**223**	223

TABLE 22. Confusion matrix fold 10

Actual label \ Predicted label	WA	WU	WD	SI	ST	LA	Sup.
WA	**99.4%**	0.6%	0.0%	0.0%	0.0%	0.0%	
	171	1	0	0	0	0	172
WU	0.0%	**100.0%**	0.0%	0.0%	0.0%	0.0%	
	0	**165**	0	0	0	0	165
WD	0.0%	0.0%	**100.0%**	0.0%	0.0%	0.0%	
	0	0	**156**	0	0	0	156
SI	0.0%	0.0%	0.0%	**87.1%**	12.9%	0.0%	
	0	0	0	**169**	25	0	194
ST	0.0%	0.0%	0.0%	3.9%	**96.1%**	0.0%	
	0	0	0	8	**195**	0	203
LA	0.0%	0.0%	0.0%	0.0%	0.0%	**100.0%**	
	0	0	0	0	0	**219**	219