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

I. APPENDIX: STRATIFIED 10-FOLD CROSS-VALIDATION

This appendix presents results on the stratified 10-fold cross-validation study. This information extends the experimental results of the original paper. To create the stratified training and test sets we used the following Python function:

https://scikit-learn.org/stable/modules/generated/sklearn.model_selection.StratifiedGroupKFold.html

where one group corresponds to one of our participants. This avoids the repetition of samples of the same participant in the test and training data. 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. Stratified Cross-Validation: Fold 1

Classes	Precision	Recall	F1-Score	Support
WA	1.000	1.000	1.000	166
WU	1.000	1.000	1.000	153
WD	1.000	1.000	1.000	140
SI	0.994	0.889	0.939	189
ST	0.906	0.995	0.948	203
LA	1.000	1.000	1.000	209

TABLE 2. Stratified Cross-Validation: Fold 2

Classes	Precision	Recall	F1-Score	Support
WA	1.000	1.000	1.000	168
WU	1.000	1.000	1.000	155
WD	1.000	1.000	1.000	143
SI	0.988	0.966	0.977	175
ST	0.969	0.989	0.979	189
LA	1.000	1.000	1.000	184

TABLE 3. Stratified Cross-Validation: Fold 3

Classes	Precision	Recall	F1-Score	Support
WA	1.000	1.000	1.000	185
WU	1.000	1.000	1.000	167
WD	1.000	1.000	1.000	151
SI	0.928	0.832	0.877	185
ST	0.862	0.942	0.900	206
LA	1.000	1.000	1.000	205

TABLE 4. Stratified Cross-Validation: Fold 4

Classes	Precision	Recall	F1-Score	Support
WA	1.000	0.717	0.835	159
WU	0.762	1.000	0.865	144
WD	1.000	1.000	1.000	123
SI	0.989	0.989	0.989	175
ST	0.989	0.989	0.989	176
LA	1.000	1.000	1.000	195

TABLE 5. Stratified Cross-Validation: Fold 5

Classes	Precision	Recall	F1-Score	Support
WA	1.000	1.000	1.000	172
WU	1.000	1.000	1.000	174
WD	1.000	1.000	1.000	164
SI	0.857	0.957	0.905	188
ST	0.957	0.857	0.905	210
LA	1.000	1.000	1.000	205

TABLE 6. Stratified Cross-Validation: Fold 6

Classes	Precision	Recall	F1-Score	Support
WA	1.000	0.841	0.914	164
WU	1.000	0.837	0.911	141
WD	0.715	1.000	0.834	123
SI	0.982	0.900	0.939	180
ST	0.899	0.982	0.939	164
LA	1.000	1.000	1.000	198

TABLE 7. Stratified Cross-Validation: Fold 7

Classes	Precision	Recall	F1-Score	Support
WA	1.000	1.000	1.000	163
WU	1.000	1.000	1.000	151
WD	1.000	1.000	1.000	131
SI	0.916	0.976	0.945	168
ST	0.978	0.923	0.950	195
LA	1.000	1.000	1.000	190

TABLE 8. Stratified Cross-Validation: Fold 8

Classes	Precision	Recall	F1-Score	Support
WA	1.000	1.000	1.000	171
WU	0.987	1.000	0.994	156
WD	1.000	1.000	1.000	143
SI	0.971	0.934	0.952	182
ST	0.949	0.974	0.961	192
LA	1.000	1.000	1.000	193

TABLE 9. Stratified Cross-Validation: Fold 9

Classes	Precision	Recall	F1-Score	Support
WA	1.000	1.000	1.000	208
WU	1.000	1.000	1.000	154
WD	1.000	1.000	1.000	142
SI	0.969	0.987	0.978	157
ST	0.988	0.971	0.980	174
LA	1.000	1.000	1.000	173

TABLE 10. Stratified Cross-Validation: Fold 10

Classes	Precision	Recall	F1-Score	Support
WA	1.000	1.000	1.000	166
WU	1.000	1.000	1.000	149
WD	1.000	1.000	1.000	146
SI	0.881	0.994	0.934	178
ST	0.994	0.878	0.933	197
LA	1.000	1.000	1.000	192

TABLE 11. Stratified Cross-Validation: Accuracy, F1-Score Average, F1-Score Weighted, and support.

Fold	Accuracy	F1-Score Average	F1-Score Weighted	Support
1	0.979	0.981	0.979	1060
2	0.992	0.993	0.992	1014
3	0.961	0.963	0.961	1099
4	0.950	0.946	0.949	972
5	0.966	0.968	0.966	1113
6	0.928	0.923	0.930	970
7	0.981	0.983	0.981	998
8	0.984	0.985	0.984	1037
9	0.993	0.993	0.993	1008
10	0.976	0.978	0.976	1028
Average	0.971	0.971	0.971	-

TABLE 12. Summary table of the stratified cross-validation 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. Participant ID refers to the ID of the participant belonging to the test set in each fold.

Fold	Precision	Recall	F1-Score	Participant ID
1	0.983 ± 0.038	0.981 ± 0.045	0.981 ± 0.029	6, 13, 21
2	0.993 ± 0.013	0.993 ± 0.014	0.993 ± 0.011	1, 4, 29
3	0.965 ± 0.058	0.962 ± 0.068	0.963 ± 0.058	7, 25, 28
4	0.957 ± 0.096	0.949 ± 0.114	0.946 ± 0.075	14, 15, 22
5	0.969 ± 0.057	0.969 ± 0.057	0.968 ± 0.049	16, 18, 30
6	0.933 ± 0.114	0.927 ± 0.077	0.923 ± 0.054	10, 11, 19
7	0.982 ± 0.034	0.983 ± 0.031	0.983 ± 0.027	3, 8, 27
8	0.985 ± 0.021	0.985 ± 0.027	0.985 ± 0.022	9, 17, 24
9	0.993 ± 0.013	0.993 ± 0.012	0.993 ± 0.011	2, 12, 26
10	0.979 ± 0.048	0.979 ± 0.049	0.978 ± 0.034	5, 20, 23

TABLE 13. Confusion matrix stratified cross-validation: 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%	
		166	0	0	0	0	0	166
	WU	0.0%	**100.0%**	0.0%	0.0%	0.0%	0.0%	
		0	**153**	0	0	0	0	153
	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%	**88.9%**	11.1%	0.0%	
		0	0	0	**168**	21	0	189
	ST	0.0%	0.0%	0.0%	0.5%	**99.5%**	0.0%	
		0	0	0	1	**202**	0	203
	LA	0.0%	0.0%	0.0%	0.0%	0.0%	**100.0%**	
		0	0	0	0	0	**209**	209

TABLE 14. Confusion matrix stratified cross-validation: 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%	
		168	0	0	0	0	0	168
	WU	0.0%	**100.0%**	0.0%	0.0%	0.0%	0.0%	
		0	**155**	0	0	0	0	155
	WD	0.0%	0.0%	**100.0%**	0.0%	0.0%	0.0%	
		0	0	**143**	0	0	0	143
	SI	0.0%	0.0%	0.0%	**96.6%**	3.4%	0.0%	
		0	0	0	**169**	6	0	175
	ST	0.0%	0.0%	0.0%	1.1%	**98.9%**	0.0%	
		0	0	0	2	**187**	0	189
	LA	0.0%	0.0%	0.0%	0.0%	0.0%	**100.0%**	
		0	0	0	0	0	**184**	184

TABLE 15. Confusion matrix stratified cross-validation: Fold 3

Actual label \ Predicted label	WA	WU	WD	SI	ST	LA	Sup.
WA	**100.0%**	0.0%	0.0%	0.0%	0.0%	0.0%	
	185	0	0	0	0	0	185
WU	0.0%	**100.0%**	0.0%	0.0%	0.0%	0.0%	
	0	**167**	0	0	0	0	167
WD	0.0%	0.0%	**100.0%**	0.0%	0.0%	0.0%	
	0	0	**151**	0	0	0	151
SI	0.0%	0.0%	0.0%	**83.2%**	16.8%	0.0%	
	0	0	0	**154**	31	0	185
ST	0.0%	0.0%	0.0%	5.8%	**94.2%**	0.0%	
	0	0	0	12	**194**	0	206
LA	0.0%	0.0%	0.0%	0.0%	0.0%	**100.0%**	
	0	0	0	0	0	**205**	205

TABLE 16. Confusion matrix stratified cross-validation: Fold 4

Actual label \ Predicted label	WA	WU	WD	SI	ST	LA	Sup.
WA	**71.7%**	28.3%	0.0%	0.0%	0.0%	0.0%	
	114	45	0	0	0	0	159
WU	0.0%	**100.0%**	0.0%	0.0%	0.0%	0.0%	
	0	**144**	0	0	0	0	144
WD	0.0%	0.0%	**100.0%**	0.0%	0.0%	0.0%	
	0	0	**123**	0	0	0	123
SI	0.0%	0.0%	0.0%	**98.9%**	1.1%	0.0%	
	0	0	0	**173**	2	0	175
ST	0.0%	0.0%	0.0%	1.1%	**98.9%**	0.0%	
	0	0	0	2	**174**	0	176
LA	0.0%	0.0%	0.0%	0.0%	0.0%	**100.0%**	
	0	0	0	0	0	**195**	195

TABLE 17. Confusion matrix stratified cross-validation: Fold 5

Actual label \ Predicted label	WA	WU	WD	SI	ST	LA	Sup.
WA	**100.0%**	0.0%	0.0%	0.0%	0.0%	0.0%	
	172	0	0	0	0	0	172
WU	0.0%	**100.0%**	0.0%	0.0%	0.0%	0.0%	
	0	**174**	0	0	0	0	174
WD	0.0%	0.0%	**100.0%**	0.0%	0.0%	0.0%	
	0	0	**164**	0	0	0	164
SI	0.0%	0.0%	0.0%	**95.7%**	4.3%	0.0%	
	0	0	0	**180**	8	0	188
ST	0.0%	0.0%	0.0%	14.3%	**85.7%**	0.0%	
	0	0	0	30	**180**	0	210
LA	0.0%	0.0%	0.0%	0.0%	0.0%	**100.0%**	
	0	0	0	0	0	**205**	205

TABLE 18. Confusion matrix stratified cross-validation: Fold 6

Actual label \ Predicted label	WA	WU	WD	SI	ST	LA	Sup.
WA	**84.1%**	0.0%	15.9%	0.0%	0.0%	0.0%	
	138	0	26	0	0	0	164
WU	0.0%	**83.7%**	16.3%	0.0%	0.0%	0.0%	
	0	**118**	23	0	0	0	141
WD	0.0%	0.0%	**100.0%**	0.0%	0.0%	0.0%	
	0	0	**123**	0	0	0	123
SI	0.0%	0.0%	0.0%	**90.0%**	10.0%	0.0%	
	0	0	0	**162**	18	0	180
ST	0.0%	0.0%	0.0%	1.8%	**98.2%**	0.0%	
	0	0	0	3	**161**	0	164
LA	0.0%	0.0%	0.0%	0.0%	0.0%	**100.0%**	
	0	0	0	0	0	**198**	198

TABLE 19. Confusion matrix stratified cross-validation: 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%	
	163	0	0	0	0	0	163
WU	0.0%	**100.0%**	0.0%	0.0%	0.0%	0.0%	
	0	**151**	0	0	0	0	151
WD	0.0%	0.0%	**100.0%**	0.0%	0.0%	0.0%	
	0	0	**131**	0	0	0	131
SI	0.0%	0.0%	0.0%	**97.6%**	2.4%	0.0%	
	0	0	0	**164**	4	0	168
ST	0.0%	0.0%	0.0%	7.7%	**92.3%**	0.0%	
	0	0	0	15	**180**	0	195
LA	0.0%	0.0%	0.0%	0.0%	0.0%	**100.0%**	
	0	0	0	0	0	**190**	190

TABLE 20. Confusion matrix stratified cross-validation: 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%	
	171	0	0	0	0	0	171
WU	0.0%	**100.0%**	0.0%	0.0%	0.0%	0.0%	
	0	**156**	0	0	0	0	156
WD	0.0%	0.0%	**100.0%**	0.0%	0.0%	0.0%	
	0	0	**143**	0	0	0	143
SI	0.0%	1.1%	0.0%	**93.4%**	5.5%	0.0%	
	0	2	0	**170**	10	0	182
ST	0.0%	0.0%	0.0%	2.6%	**97.4%**	0.0%	
	0	0	0	5	**187**	0	192
LA	0.0%	0.0%	0.0%	0.0%	0.0%	**100.0%**	
	0	0	0	0	0	**193**	193

TABLE 21. Confusion matrix stratified cross-validation: 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%	
	208	0	0	0	0	0	208
WU	0.0%	**100.0%**	0.0%	0.0%	0.0%	0.0%	
	0	**154**	0	0	0	0	154
WD	0.0%	0.0%	**100.0%**	0.0%	0.0%	0.0%	
	0	0	**142**	0	0	0	142
SI	0.0%	0.0%	0.0%	**98.7%**	1.3%	0.0%	
	0	0	0	**155**	2	0	157
ST	0.0%	0.0%	0.0%	2.9%	**97.1%**	0.0%	
	0	0	0	5	**169**	0	174
LA	0.0%	0.0%	0.0%	0.0%	0.0%	**100.0%**	
	0	0	0	0	0	**173**	173

TABLE 22. Confusion matrix stratified cross-validation: Fold 10

Actual label \ Predicted label	WA	WU	WD	SI	ST	LA	Sup.
WA	**100.0%**	0.0%	0.0%	0.0%	0.0%	0.0%	
	166	0	0	0	0	0	166
WU	0.0%	**100.0%**	0.0%	0.0%	0.0%	0.0%	
	0	**149**	0	0	0	0	149
WD	0.0%	0.0%	**100.0%**	0.0%	0.0%	0.0%	
	0	0	**146**	0	0	0	146
SI	0.0%	0.0%	0.0%	**99.4%**	0.6%	0.0%	
	0	0	0	**177**	1	0	178
ST	0.0%	0.0%	0.0%	12.2%	**87.8%**	0.0%	
	0	0	0	24	**173**	0	197
LA	0.0%	0.0%	0.0%	0.0%	0.0%	**100.0%**	
	0	0	0	0	0	**192**	192