Neural Network-based automated ECG Delineation

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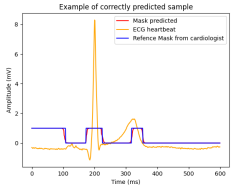
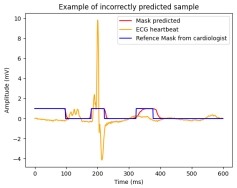
ECG delineation is a key step for assessing drug-induced proarrhythmic risk. Despite the development of automated analysis algorithms, ECGs are still currently performed by expert cardiologists. Our study explores the use of deep learning for accurate localization of the following ECG fiducial points: P_{onset}, QRS_{onset}, QRS_{offset}, T_{peak} and T_{end}.

We proposed an adapted U-Net architecture, devoid of skip connections, bottleneck and upsampling to reduce computational time and mitigate overfitting. Operating on 1.2s single-lead ECG templates sampled at 500Hz, it produces binary masks of the size of ECG input which are defined such that each transition from 0 to 1 or 1 to 0 corresponds to a fiducial of interest. For training, we conducted a 5-fold patient stratified cross-validation on 2,054 12-lead ECGs from Verapamil(V) and Quinidine(Q) studies in the ECGRDVQ database available on PhysioNet. The proposed model was tested on 13,088 12- lead ECGs from 12 other drug studies in the following PhysioNet databases: ECGRDVQ (Ranolazine(R), Dofetilide (D) and Placebo (P)), CiPA and ECGDMMLD.

Our proposed approach was compared with a traditional U-Net, a Wavelet technique and a ResNet-based model. The proposed model achieved best overall results and yields small mean absolute differences with cardiologist measurements on the global test set: 3.86 ± 2.9 ms for the QRS_{onset} to 6.77 ± 7.41 ms for the T_{peak}.

Our model seems promising for automated ECG delineation during drug safety during clinical trials, among other applications, allowing to enhance clinical workflow efficiency. Further research could consist in including an uncertainty measurement of the delineation process.





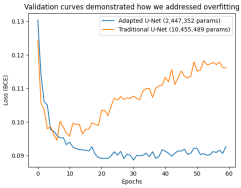


Table 1 : Comparison of Adapted U-Net with others methods for automatic ECG fiducial points localization (mean absolute error ± standard deviation). **Bold** indicates the best performer.

Test data	Methods	P_{onset}	QRS_{onset}	QRS_{offset}	T_{peak}	T_{end}	Parameters
ECGRDVQ (R,D,P)	U-Net	4.68 ± 4.02	2.77 ± 2.1	**5.44 ± 4.31**	4.85 ± 5.71	4.99 ± 6.68	10,455,489
	Wavelet	25.82 ± 16.98	24.4 ± 7.6	10.93 ± 7.39	15.38 ± 12.2	17.23 ± 16.12	.....
	ResNet	4.58 ± 4.26	**2.35 ± 1.95**	5.62 ± 4.23	6.28 ± 8.02	7.12 ± 9.1	1,656,066
	Adapted U-Net	**4.2 ± 3.79**	2.89 ± 2.12	5.45 ± 4.63	**4.31 ± 5.44**	**4.31 ± 6.64**	2,447,352
ECGDMMLD	U-Net	6.53 ± 4.71	**2.86 ± 2.03**	9.81 ± 6.09	**6.91 ± 6.51**	**5.95 ± 4.47**	
	Wavelet	33.84 ± 18.46	26.62 ± 8.26	18.81 ± 10.75	22.61 ± 15.26	15.08 ± 12.15	
	ResNet	6.6 ± 5.75	2.98 ± 1.97	10.83 ± 6.05	10.79 ± 9.8	6.37 ± 6.6	
	Adapted U-Net	**5.91 ± 4.48**	3.22 ± 2.07	**8.52 ± 5.83**	6.98 ± 7.84	6.05 ± 4.48	
CiPA	U-Net	5.13 ± 4.97	4.71 ± 3.32	5.72 ± 4.51	**7.49 ± 7.88**	6.83 ± 7.11	
	Wavelet	31.7 ± 19.5	20.94 ± 7.23	12.49 ± 8.32	17.66 ± 15.23	17.3 ± 13.8	
	ResNet	5.99 ± 7.12	**4.19 ± 2.93**	6.53 ± 4.94	9.0 ± 10.19	10.18 ± 9.13	
	Adapted U-Net	**4.69 ± 4.47**	4.86 ± 3.42	**5.44 ± 3.99**	7.97 ± 7.7	**6.75 ± 6.97**	