AI-based 3-Lead to 12-Lead ECG Reconstruction: Towards Smartphone-based Public Healthcare

Presenter

S.D. Neelapala

IIT Hyderabad

Co-Authors: A. Mallick, Rahul L.R., A. Shaiju, L. Giri, R. Sarkar, S. Jana

Introduction

Cardiovascular diseases (CVDs) **are a group of disorders of heart and blood vessels that can lead to heart attack and stroke**

#1

CVDs are the leading cause of death worldwide

1 out of 3

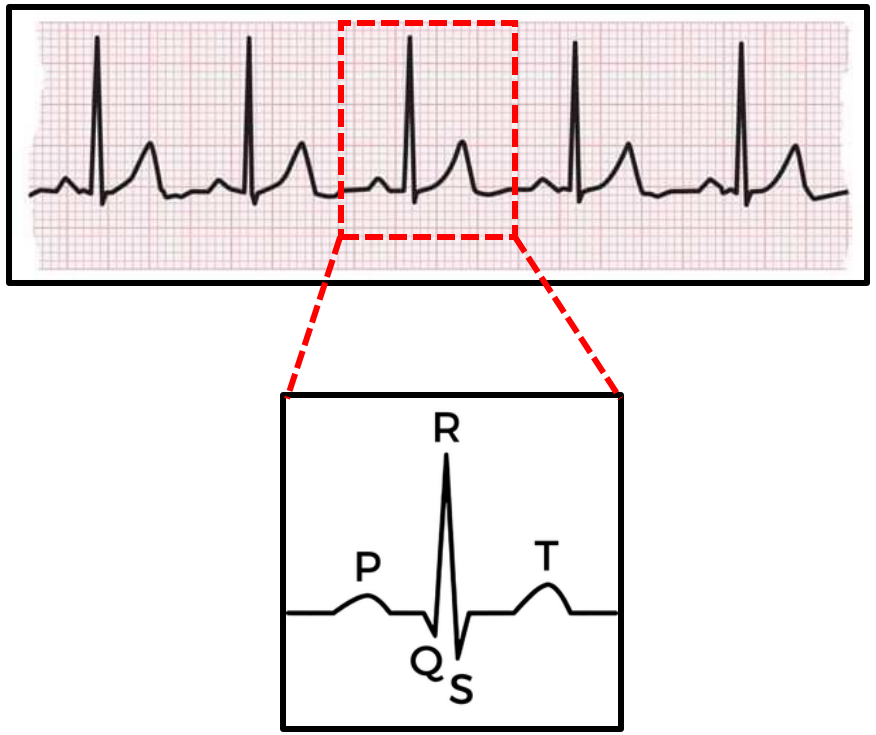
deaths worldwide are due to CVDs

3 out of 4

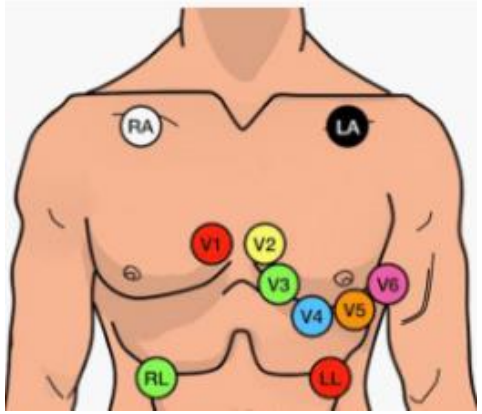
deaths from CVDs occur in low- and middle-income countries

Early diagnosis of CVD is crucial to avoid catastrophic conditions

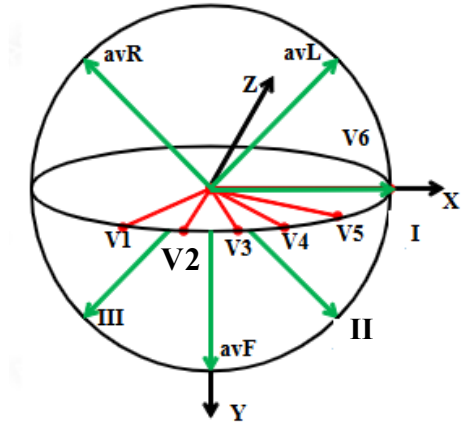
Electrocardiogram (ECG) **is the most popular non-invasive method for diagnosis of CVDs**



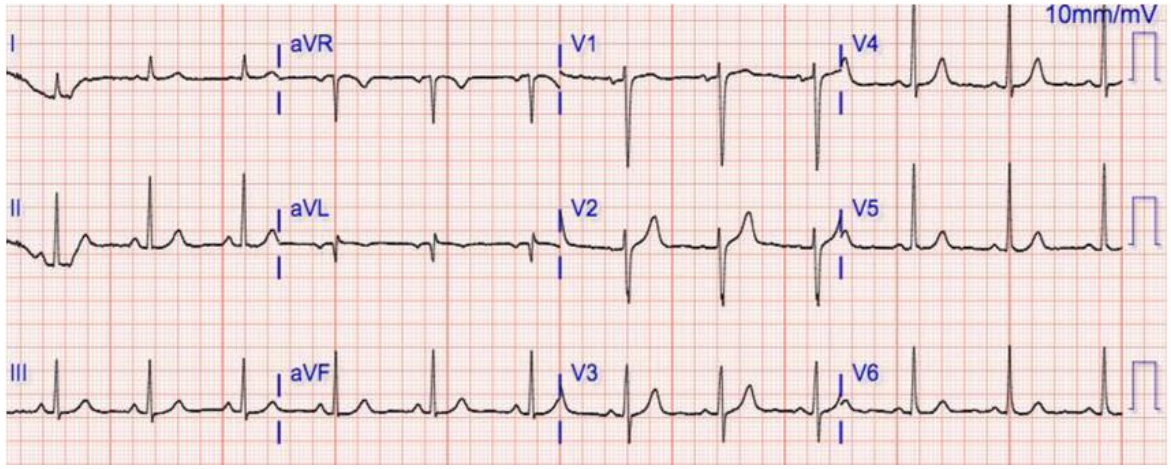
Standard 12-lead (S12L) ECG



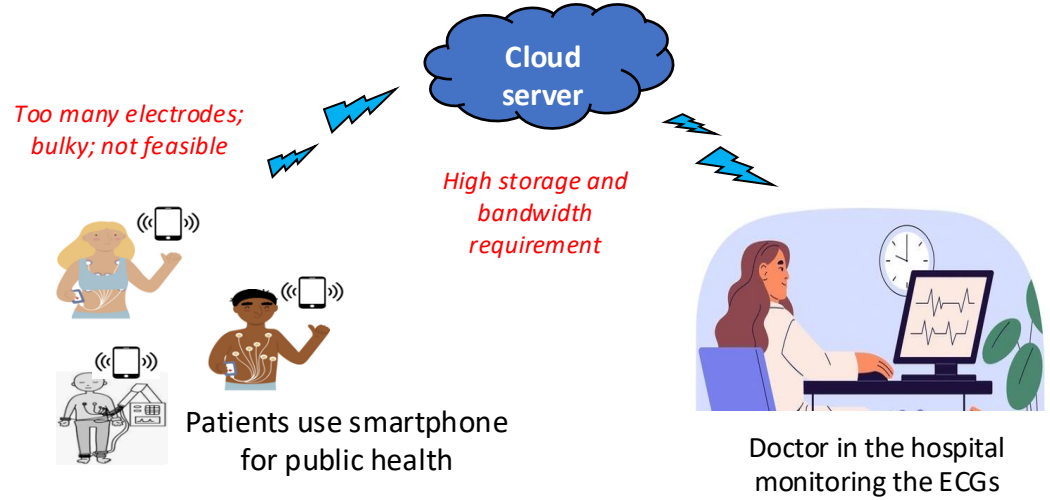
- The clinically accepted ECG lead system
- Clinicians are trained to diagnose using S12L ECG



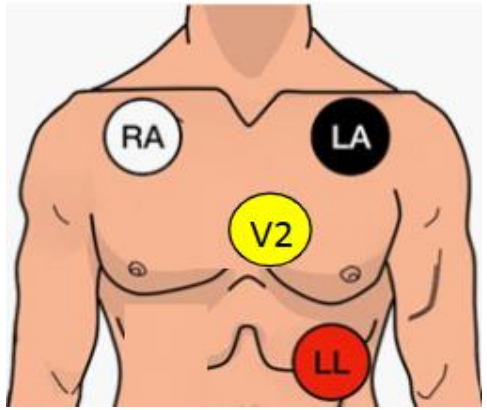
- Provides comprehensive 3D information of heart from all directions



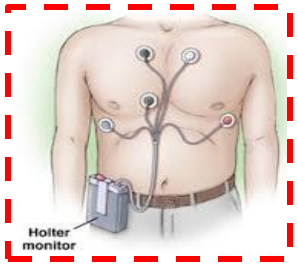
Mobile-based public health challenges

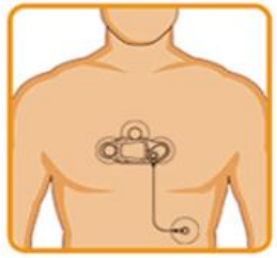


Reduced lead (RL) ECG



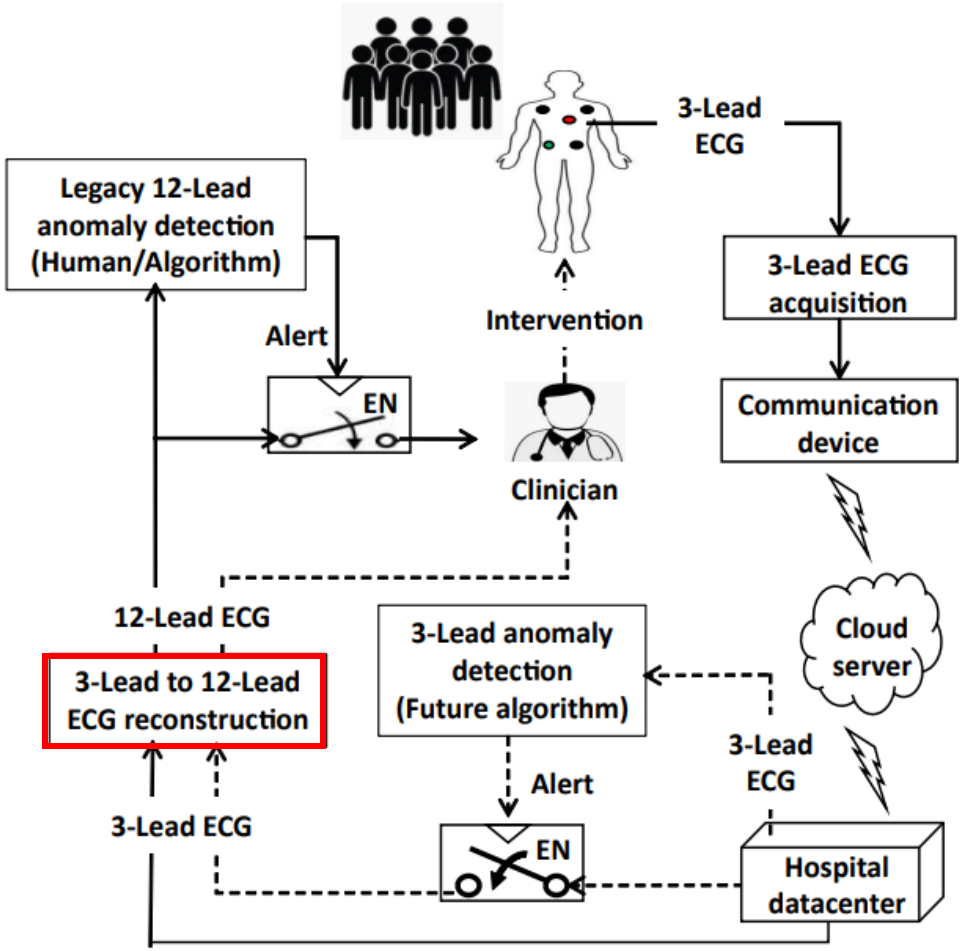
- This uses a subset of S12L ECG system
- Used for specific clinical, wellness or monitoring needs





Reduced 3-lead (R3L) ECG widely used in remote cardiac monitoring, and **single lead ECGs** are used in wearable devices for wellness monitoring

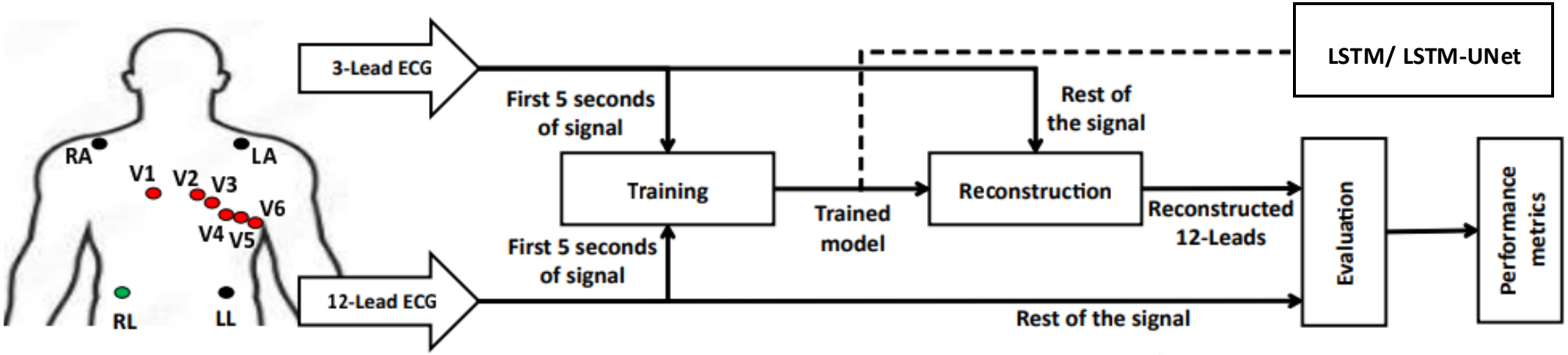
Envisaged block schematic for public health



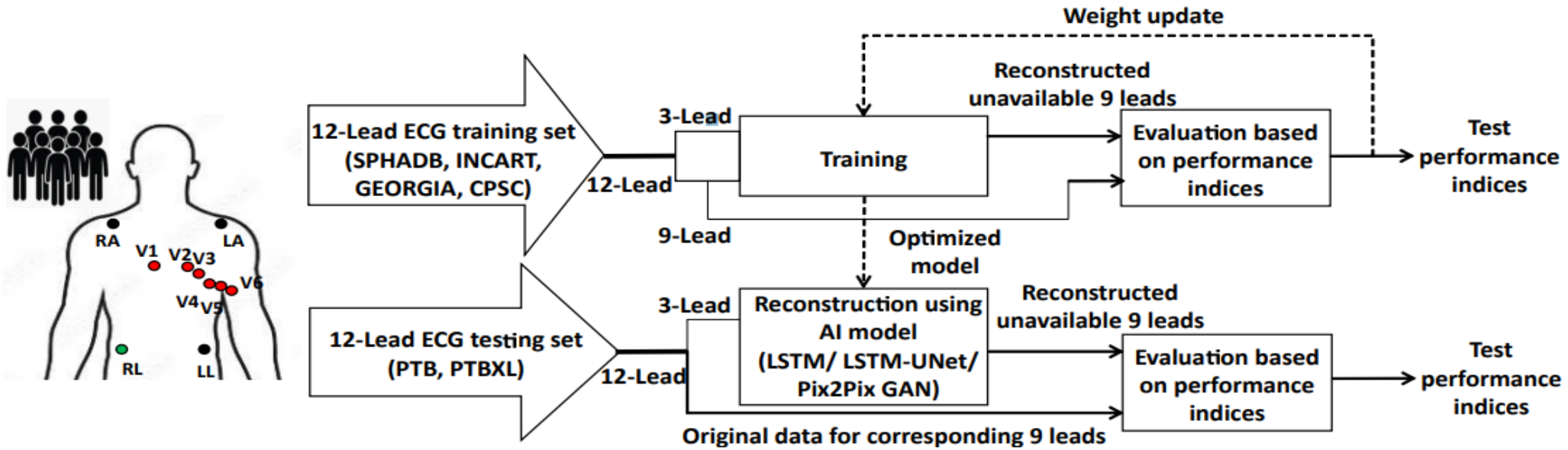
Literature review

System that employ a subset of leads (Reduced lead set) from 12-Lead ECG are only considered					
Year	**Author**	**Source leads**	**Synthesis method**	**Personalization**	**No. of subjects with accompanied diagnosis**
1989	Scherer *et al* [3].	I, II, V2	LT	Yes	12 (UH)
2002	Wei *at al* [4].	I, II, V1, V6	LT	Yes	113 (HC)
2004	Nelwan *at al* [5].	I, II, V2, V5	LT	Yes	38 (UH)
2013	A. Acharyya *et al* [7].	I, II, V2	LT	Yes	PTBDB: 51 (HC), 226 (UH) INCARTDB: 32 (UH)
2019	WANG *et al* [6].	I, II, V2	CNN	Yes	PTBDB: 51 (HC), 226 (UH)
2020	Yang *et al* [8].	I, II, V2	LSTM	Yes	30 (HC), 30 (UH)
2023	Rahul *et al* [9]	I, II, V2	LSTM-UNet	Yes	PTBDB: 51 (HC), 226 (UH) INCARTDB: 32 (UH)

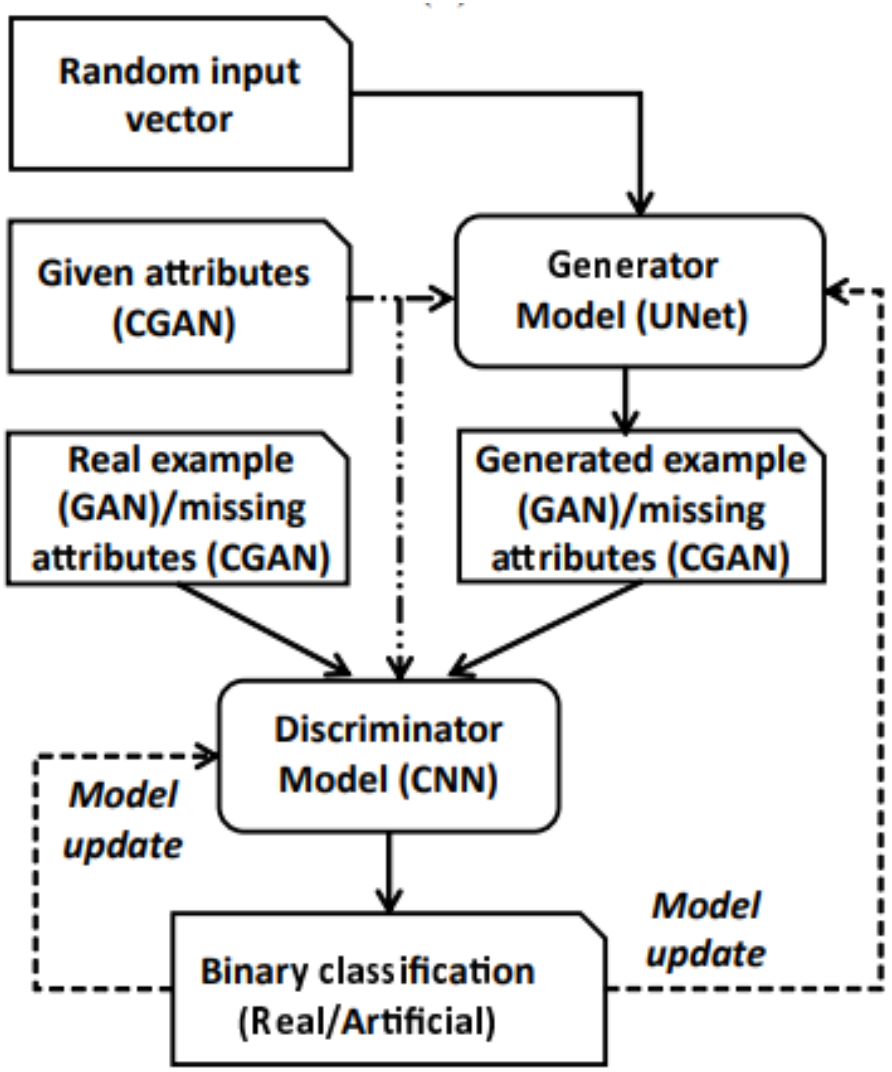
Methodology for Personalized setting (considered as reference)



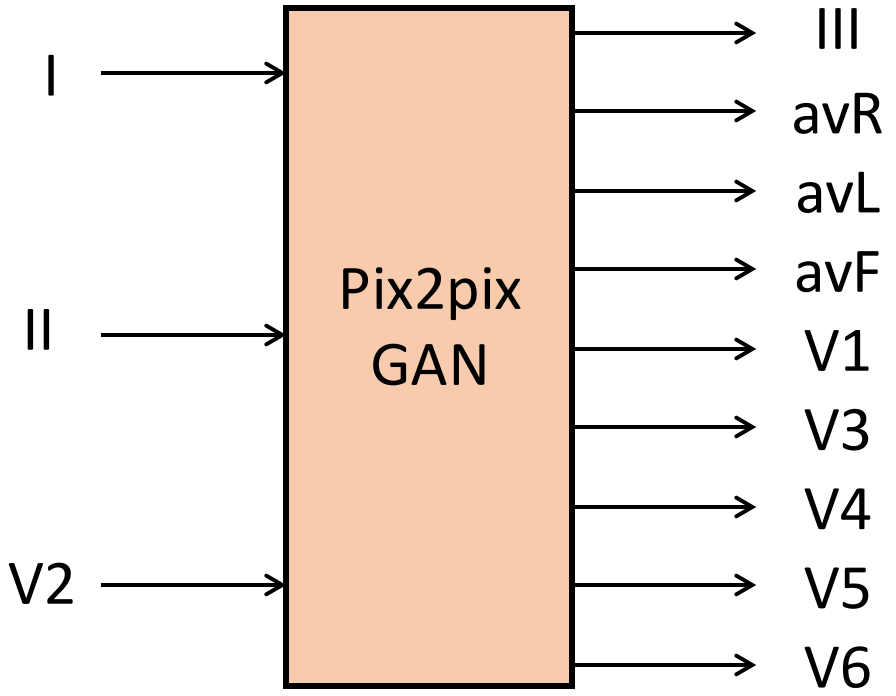
Methodology for Public setting



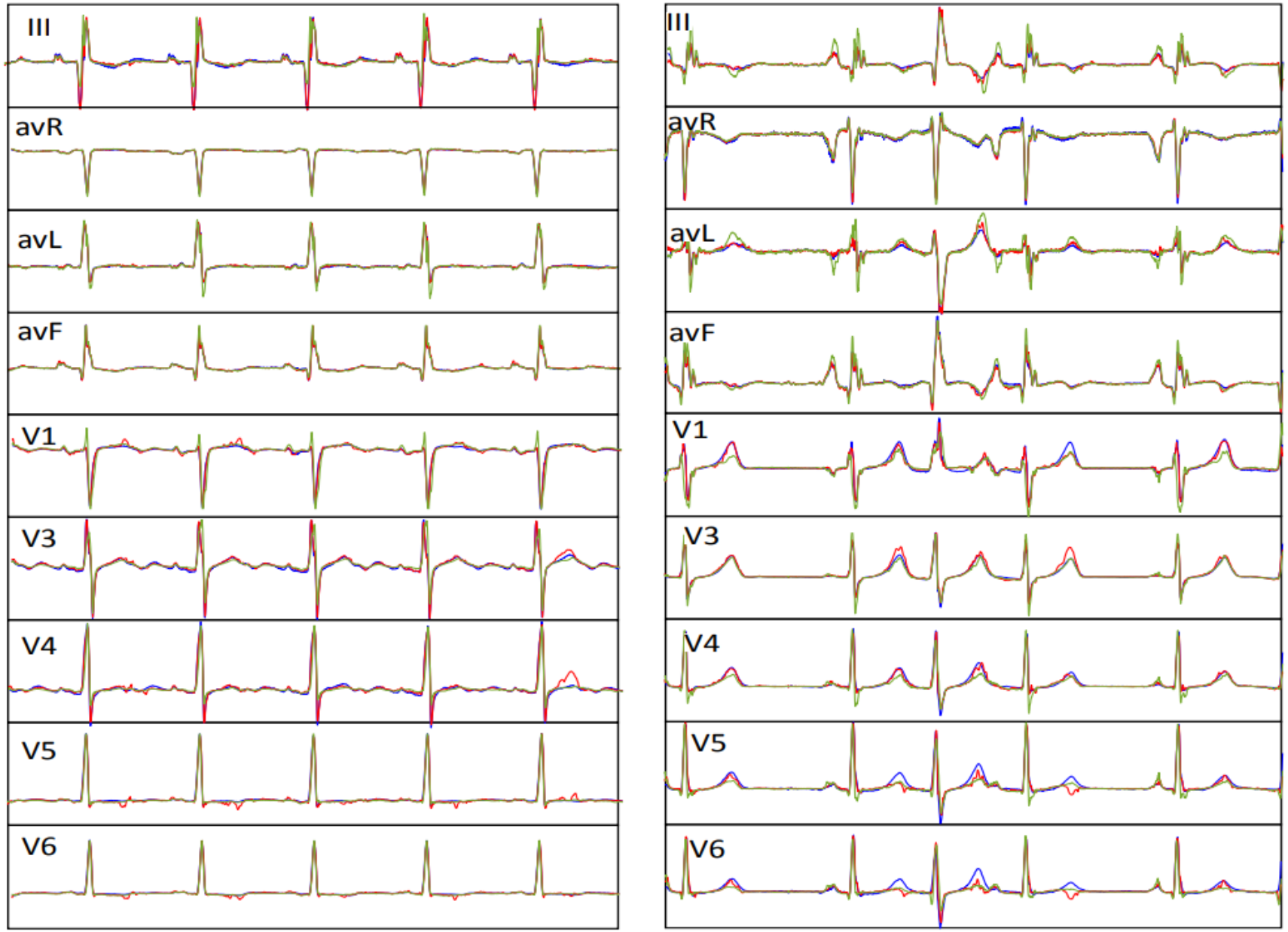
Pix2pix GAN



- A type of generative adversarial network (GAN)
- It has a conditional GAN structure that uses paired training inputs to learn to find missing leads



Results (visual comparison in PTB)



Blue: Original ECG.

Green: Reference reconstruction using LSTM-UNet in personalized setting.

Red: Proposed reconstruction using pix2pix GAN in public setting.

Results on PTB and PTBXL

(a) LSTM; (b) LSTM-UNet; (c) pix2pix GAN; (d) LSTM-UNet in personalized setting.

	PTBXL						PTB							
	R^2			r_x			R^2				r_x			
Lead	a	b	c	a	b	c	a	b	c	d	a	b	c	d
III	0.6050	0.6466	**0.7781**	0.7125	0.7442	**0.9015**	0.7151	0.7283	**0.8878**	0.9307	0.8067	0.8740	**0.9508**	0.9677
avR	0.8680	0.9452	**0.9758**	0.9317	0.9731	**0.9917**	0.8291	0.9479	**0.9729**	0.9820	0.9112	0.9739	**0.9912**	0.9977
avL	0.7252	0.7923	**0.8311**	0.8135	0.8387	**0.9214**	0.7119	0.8289	**0.9183**	0.9565	0.8605	0.9187	**0.9660**	0.9792
avF	0.7527	0.7976	**0.9154**	0.8498	0.9007	**0.9685**	0.7572	0.8558	**0.9355**	0.9645	0.8839	0.9298	**0.9778**	0.9831
V1	0.6067	0.6423	**0.8425**	0.8072	0.8498	**0.9361**	0.7491	0.7802	**0.8221**	0.9563	0.8772	0.8998	**0.9258**	0.9785
V3	0.6551	0.6813	**0.8167**	0.8276	0.8344	**0.9181**	0.7215	0.7412	**0.8710**	0.9678	0.9012	0.9078	**0.9448**	0.9845
V4	0.6260	0.7083	**0.7808**	0.7732	0.8325	**0.8913**	0.5408	0.5599	**0.6896**	0.9332	0.6922	0.7555	**0.8484**	0.9691
V5	0.6751	0.7266	**0.8369**	0.8307	0.8722	**0.9210**	0.6190	0.6766	**0.7250**	0.9273	0.7670	0.7820	**0.8532**	0.9661
V6	0.7276	0.7735	**0.8580**	0.8582	0.8921	**0.9351**	0.6324	0.6358	**0.7763**	0.9334	0.8032	0.8417	**0.8877**	0.9686
Avg	0.6934	0.7459	**0.8484**	0.8227	0.8597	**0.9316**	0.6973	0.7505	**0.8443**	0.9501	0.8336	0.8759	**0.9273**	0.9771

Observations in PTBXL:

- Proposed GAN model has high performance compared to other models
- Lead-wise statistics: avR fairly accurate but V4 less satisfactory

Observations in PTB:

- Significant gap with the personalized setting (84.43 vs 95.01)
- For leads such as avR gap is vey less (97.29 vs 98.20)
- For lead such as V4 gap is significant (68.96 vs 93.32)

Conclusion

- Pix2pix GAN shows improved performance compared to LSTM and LSTM-UNet in the public setting
- There is still scope of improvement especially in the V1-V6 leads
- Continued research in this direction is encouraged, as minor inaccuracies in lead reconstruction would lead to misdiagnosis, potentially endangering human lives

Future work

- Explore the performance of lead reconstruction using variants of GAN models such as time-series GAN and LSTM-GAN
- Cost function can be made dependent on known lead information for better contextualization and potentially improved efficacy
- Explore whether the use of side information such as a (cheaply acquired) photoplethysmograph (PPG) channel alongside the 3-lead ECG data enhances robustness.
- Generating health alerts based on 3-lead ECG data and undertaking the present lead reconstruction task only upon alert, thus saving resources.

References

- A.H. Ribeiro et al., “Automatic diagnosis of the 12-lead ECG using a deep neural network,” Nat. Commun., vol. 11, no. 1, p. 1760, 2020.
- J.A. Scherer, J. M. Jenkins, and J. M. Nicklas, “Synthesis of the 12- lead electrocardiogram from a 3-lead subset using patient-specific transformation vectors—An algorithmic approach to computerized signal synthesis,” J. Electrocardiol., vol. 22, Suppl, pp. 128-128, 1989.
- G.E. Dower., “A lead synthesizer for the Frank system to simulate the standard 12-lead electrocardiogram.” J. Electrocardiol., vol. 1, no. 1, pp. 101–116, 1968
- D. Dawson, H. Yang, M. Malshe, ST Bukkapatnam, B. Benjamin and R. Komanduri., “Linear affine transformations between 3-lead (Frank XYZ leads) vectorcardiogram and 12-lead electrocardiogram signals,” J. Electrocardiol., vol. 42, no. 6, pp. 622–630, 2009.
- S. Maheshwari, A. Acharyya, P. Rajalakshmi, P.E. Puddu, M. Schiariti., “Accurate and reliable 3-lead to 12-lead ECG reconstruction methodology for remote health monitoring applications,” IRBM, vol. 35, no. 6, pp. 341–350, 2014.
- J. Sohn, S. Yang, J. Lee, Y. Ku, H.C. Kim., “Reconstruction of 12-lead electrocardiogram from a three-lead patch-type device using a LSTM network,” Sensors, vol. 20, no. 11, pp. 3278, 2020
- L.R. Rahul, A. Shaiju and S. Jana., “3-Lead to 12-Lead ECG Reconstruction: A Novel AI-based Spatio-Temporal Method,” 20th INDICON, pp. 957–962, 2023.