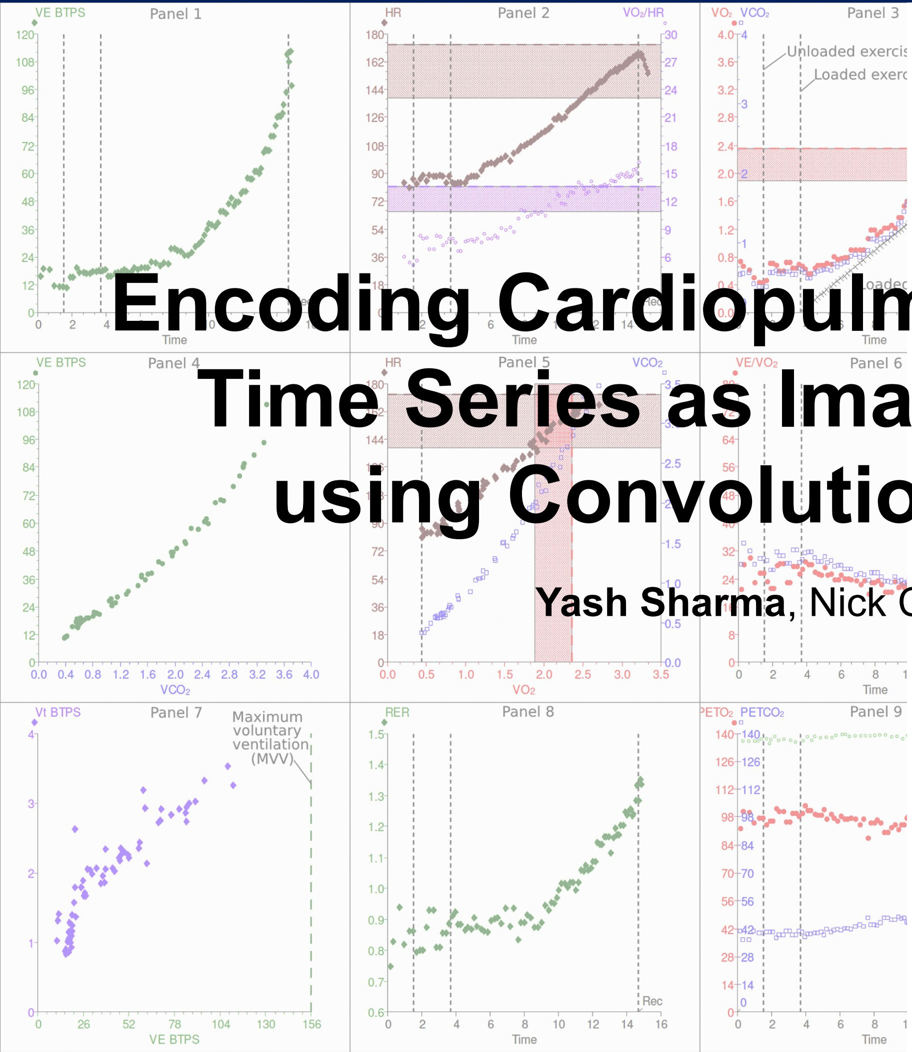

Encoding Cardiopulmonary Exercise Testing Time Series as Images for Classification using Convolutional Neural Network

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What is Exercise Testing?

Exercise testing is a remarkably versatile tool for diagnostic and prognostic information of patients for a range of diseases, especially cardiovascular and pulmonary. It is a non invasive procedure that evaluates an individual's capacity for dynamic exercises.

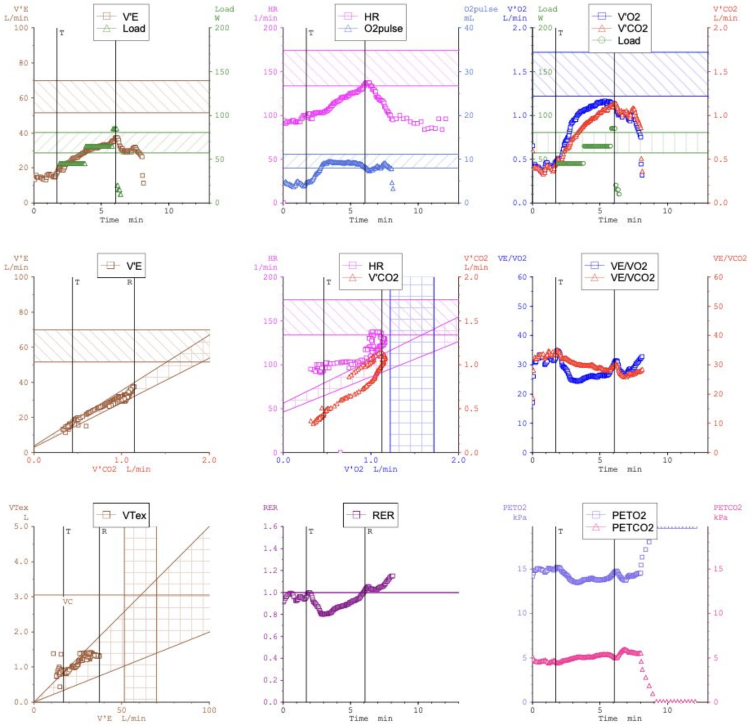
Image Reference

Cardiopulmonary Exercise Testing

- Cardiopulmonary exercise testing (CPET) is one of the commonly used laboratory tests to evaluate exercise capacity and performance levels in patients objectively.

- CPET enables the measurement of physiological response to physical exercise through an array of pulmonary, cardiovascular, and metabolic measurements built around breath-by-breath gas exchange analysis.

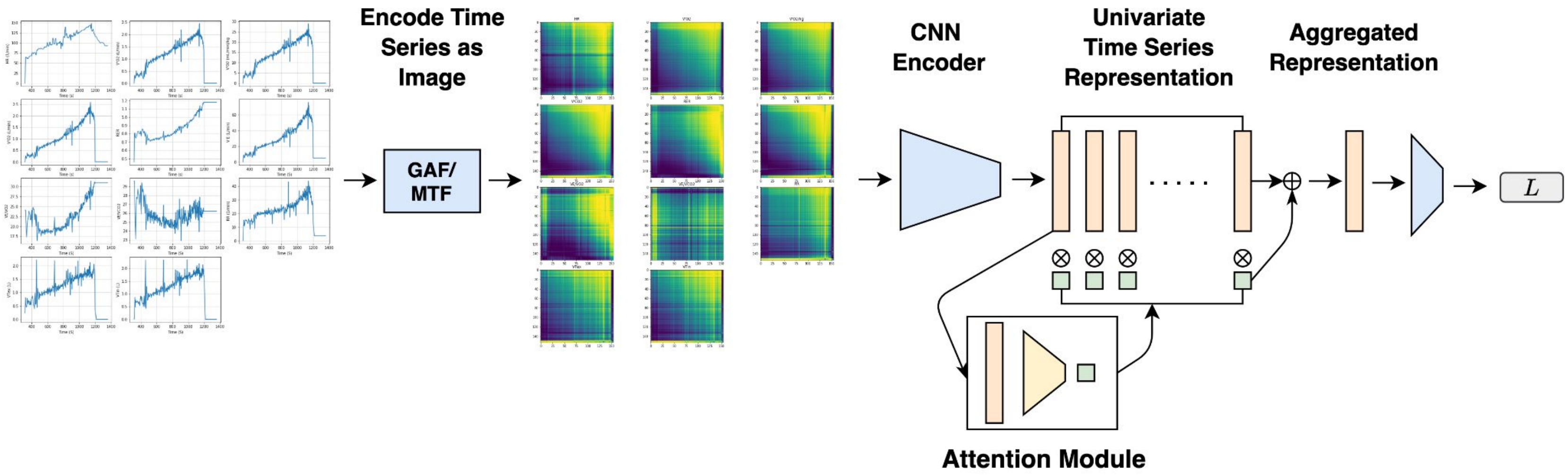
- CPET assessment is challenging, requiring the individual to process multiple time series data points, leading to simplification to peak values and slopes, concurrently ignoring relevant trends.



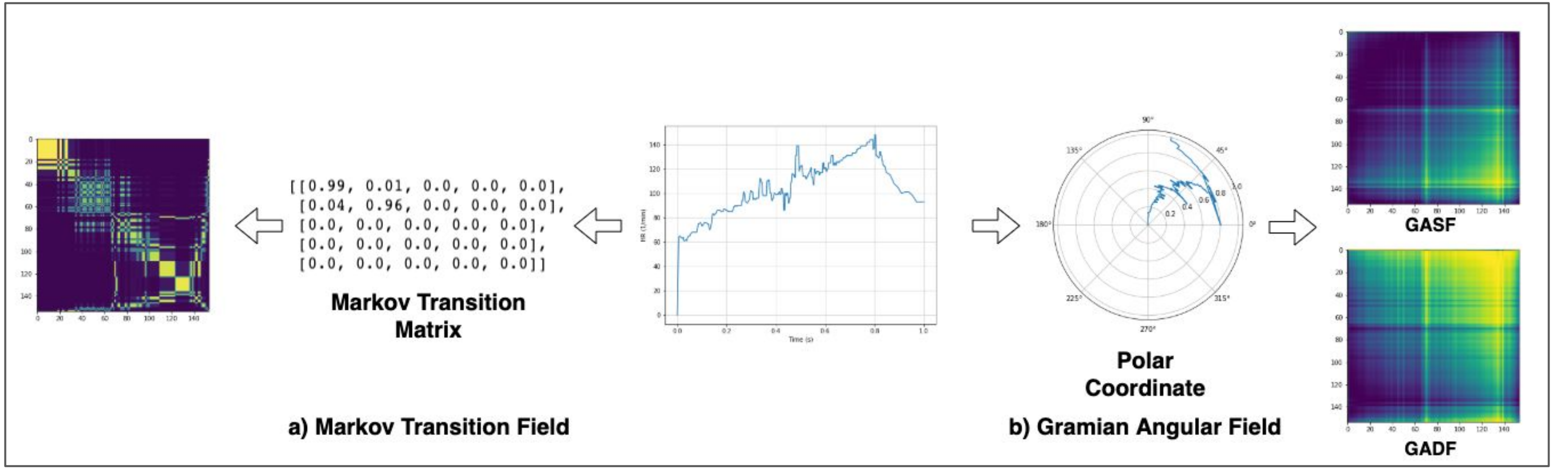
Solution!

In this work, we **encode the time series as images** using the **Gramian Angular Field** or **Markov Transition Field** and use it with a **convolutional neural network** and **attention pooling approach** for the classification of **heart failure** and **metabolic syndrome patients.**

Proposed Approach



Gramian Angular Field/ Markov Transition Field Explained



$$M = \begin{bmatrix} w_{ij|x_1 \in q_i, x_1 \in q_j} & \cdots & w_{ij|x_1 \in q_i, x_n \in q_j} \\ w_{ij|x_2 \in q_i, x_1 \in q_j} & \cdots & w_{ij|x_2 \in q_i, x_n \in q_j} \\ \vdots & \ddots & \vdots \\ w_{ij|x_n \in q_i, x_1 \in q_j} & \cdots & w_{ij|x_n \in q_i, x_n \in q_j} \end{bmatrix}$$

$$GASF = \begin{bmatrix} \cos(\phi_1 + \phi_1) & \dots & \cos(\phi_1 + \phi_n) \\ \cos(\phi_2 + \phi_1) & \dots & \cos(\phi_2 + \phi_n) \\ \vdots & \ddots & \vdots \\ \cos(\phi_n + \phi_1) & \dots & \cos(\phi_n + \phi_n) \end{bmatrix}$$

Experiments

We demonstrated this approach on two datasets:

1. **CPET dataset**
   - Consists of 30 patients diagnosed with either heart failure or metabolic syndrome (15 patients each).
   - For each patient, data contain breath-by-breath readings of the following variables: Metabolic equivalent of task (1 MET = 3.5ml/kg/min); HR (beats/min); Absolute VO2 (L/min); Relative VO2 adjusted to body mass (ml/kg/min); VCO2 (L/min); Respiratory exchange ratio; VE (L/min); VE/VCO2; VE/VO2; respiratory rate (breaths/min); expiratory tidal volume (L); and inspiratory tidal volume (L).

2. **Wafer datasets**
   - Used this open-source dataset for comparison to other approaches.
   - Collected from six vacuum chamber sensors that monitored the manufacture of semiconductor microelectronics and have two classes normal and abnormal

Wafer Dataset

- CNN-based methods on image encoded time series perform competitively to the other approaches.

- Attention pooling leads to lower error rates than the concatenation approach

- We hypothesize that for multivariate time series problems, a small CNN model on GAF/MTF based encoding of time series with attention pooling is capable of strong baselines in a limited data scenario.

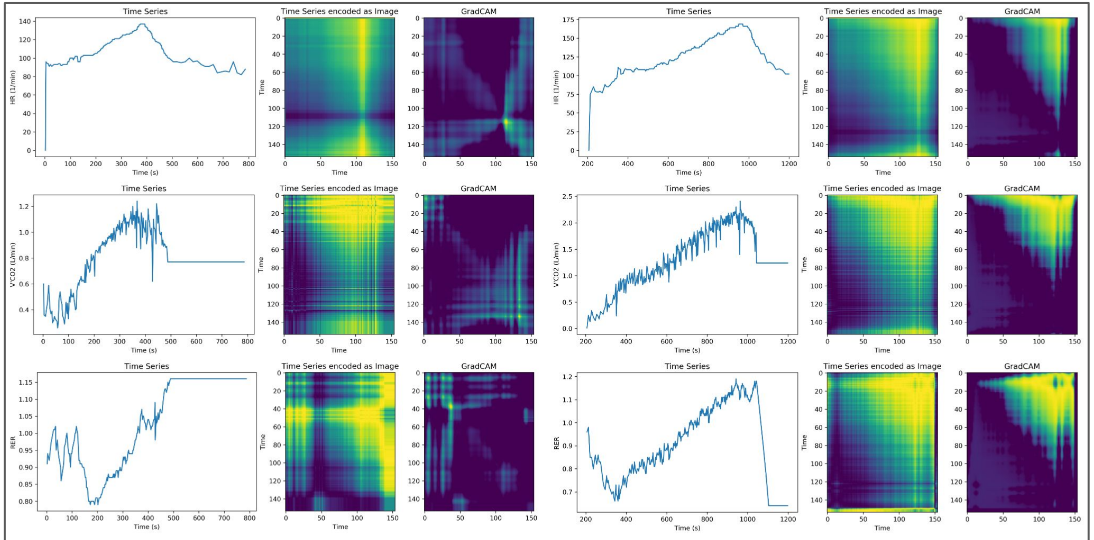
Approach	Error (%)
DTW [10]	2.01
DDTW [10]	9.21
DDDTW [10]	1.92
STKG-SVM-K3 [21]	1.23
STKG-NB-K5 [21]	3.69
STKG-IF-PSVM-DT+M [21]	0.84
STKG-IF-NB-SVM+M [21]	2.23
normDTW [16]	3.85
combDTW [16]	2.01
LSTM-FCN [15]	1.00
MLSTM-FCN [15]	1.00
ALSTM-FCN [15]	1.00
MALSTM-FCN [15]	1.00
MALSTM-FCN [15]	1.00
concat-MTF-RGB [26]	0.40
concat-GASF-RGB [26]	0.57
concat-GADF-RGB [26]	0.44
concat-MTF (ours)	0.63
concat-GASF (ours)	1.18
concat-GADF (ours)	0.46
Attn-MTF (ours)	0.41
Attn-GASF (ours)	0.55
Attn-GADF (ours)	**0.15**

CPET Dataset

Approach	Error Std. (%) Wafer	Error Std. (%) CPX
concat-MTF (ours)	0.44	5.12
concat-GASF (ours)	0.88	3.18
concat-GADF (ours)	0.73	2.72
Attn-MTF (ours)	0.14	4.15
Attn-GASF (ours)	0.18	4.51
Attn-GADF (ours)	0.18	2.13

- GAF/ MTF encoded images were able to capture the temporal trends and interactions between different time points present in time series.

- In the best-performing GADF approach, HR, RER, and V'CO2 were assigned the highest attention.



a) Heart Failure Patient

b) Metabolic Syndrome Patient

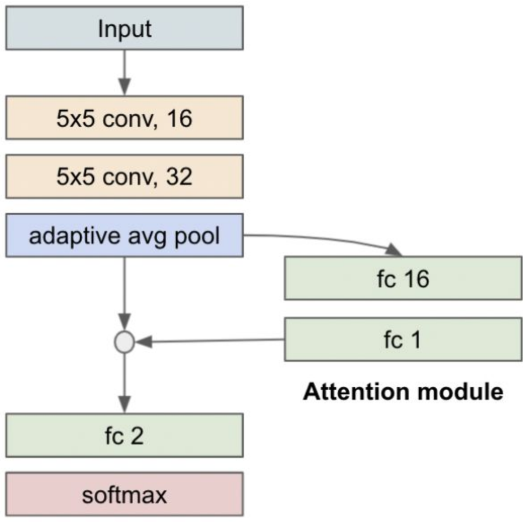
Conclusion

- Demonstrated the strong performance of **small CNNs** on CPET data for differentiating heart failure and metabolic syndrome patients.

- **GAF/ MTF based approach with CNNs** for time-series data performs **competitively** to LSTM, SVM, and DTW-based approaches.

- **Attention pooling** approach could be used with GAF/MTF approaches to aggregate univariate time series representation.

- With the advancement in the internet of things and wearables, a large amount of fitness data is getting collected, which can be used with deep learning modeling to diagnose diseases. Similar approaches like ours can aid experts in identifying markers relevant for the early diagnosis of health conditions.



Thank you!

- **Code:** https://github.com/YashSharma/MultivariateTimeSeries
- **Feel free to reach out!**
  - **Yash** Sharma (ys5hd@virgina.edu or https://yashsharma.github.io)
- **Gastroenterology Lab**: https://gastrodatasciencelab.org