quantum machine learning

time series forcasting
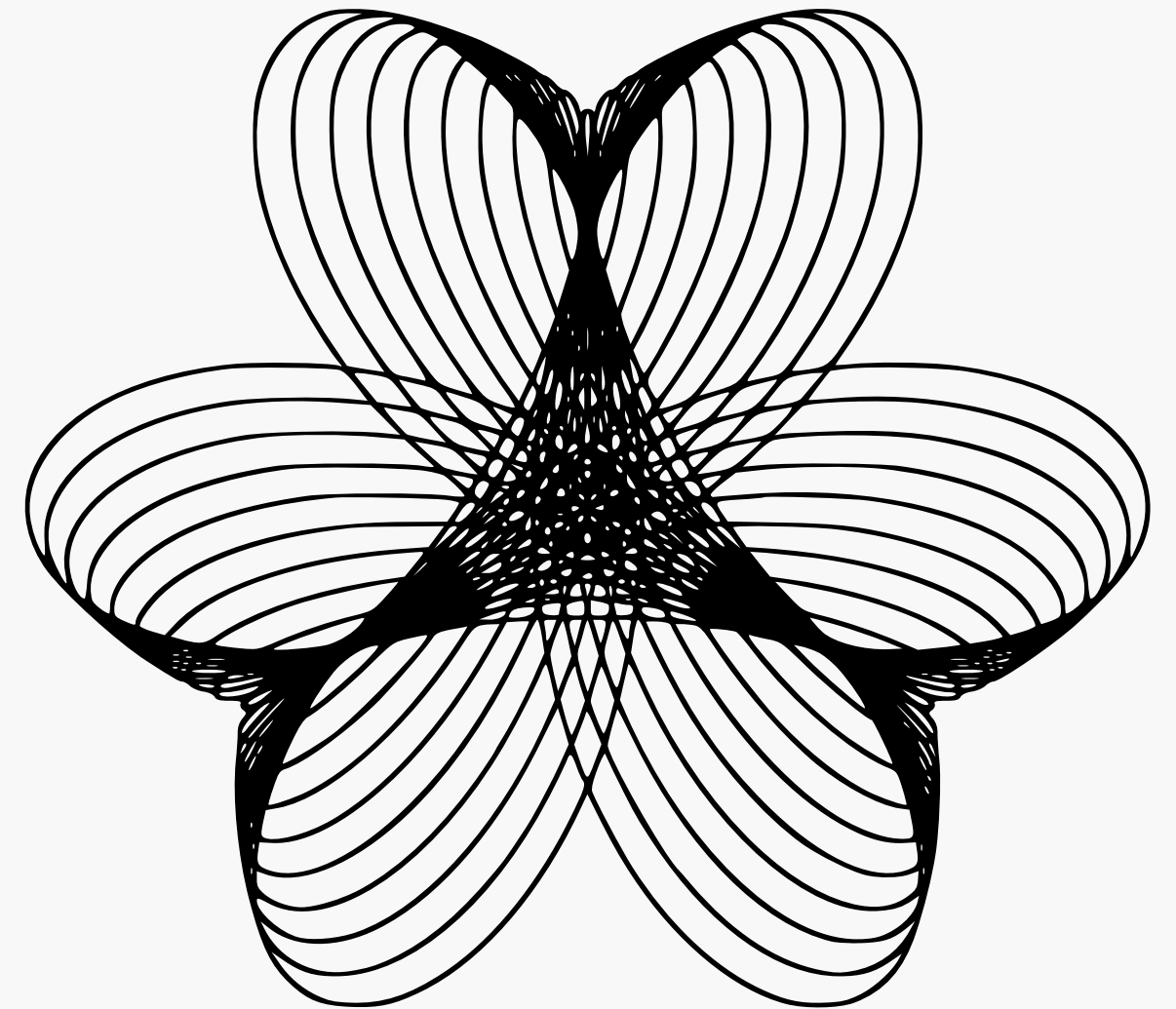
Background knowledge

QUANTUM

Hilbert space

Unitary operator - reversible

Superposition

Entanglement

Measurement - collapse

→ Quantum gates

MACHINE LEARNING

Problem Definition (classification, regression,...)

Data Preparation

Model Design

Training

Evaluation & Deployment

QUANTUM MACHINE LEARNING

QUANTUM NEURAL NETWORK

Quantum encoding: Angle, Amplitude, Basic, Phase

Variational Quantum Circuits: (sequence of gates)

- Embedding

- Rotation layers

- Entanglement

- Measurement

Dataset

Sunspot: số lượng vết đen mặt trời - **SIDC** *1749-2025, hằng tháng*

những vùng tối trên bề mặt mặt trời có từ trường mạnh, liên quan đến các hiện tượng như bão mặt trời, biến đổi khí hậu và ảnh hưởng đến hệ thống điện – viễn thông trên Trái Đất.

Monthly Sunspot Numbers Over Time
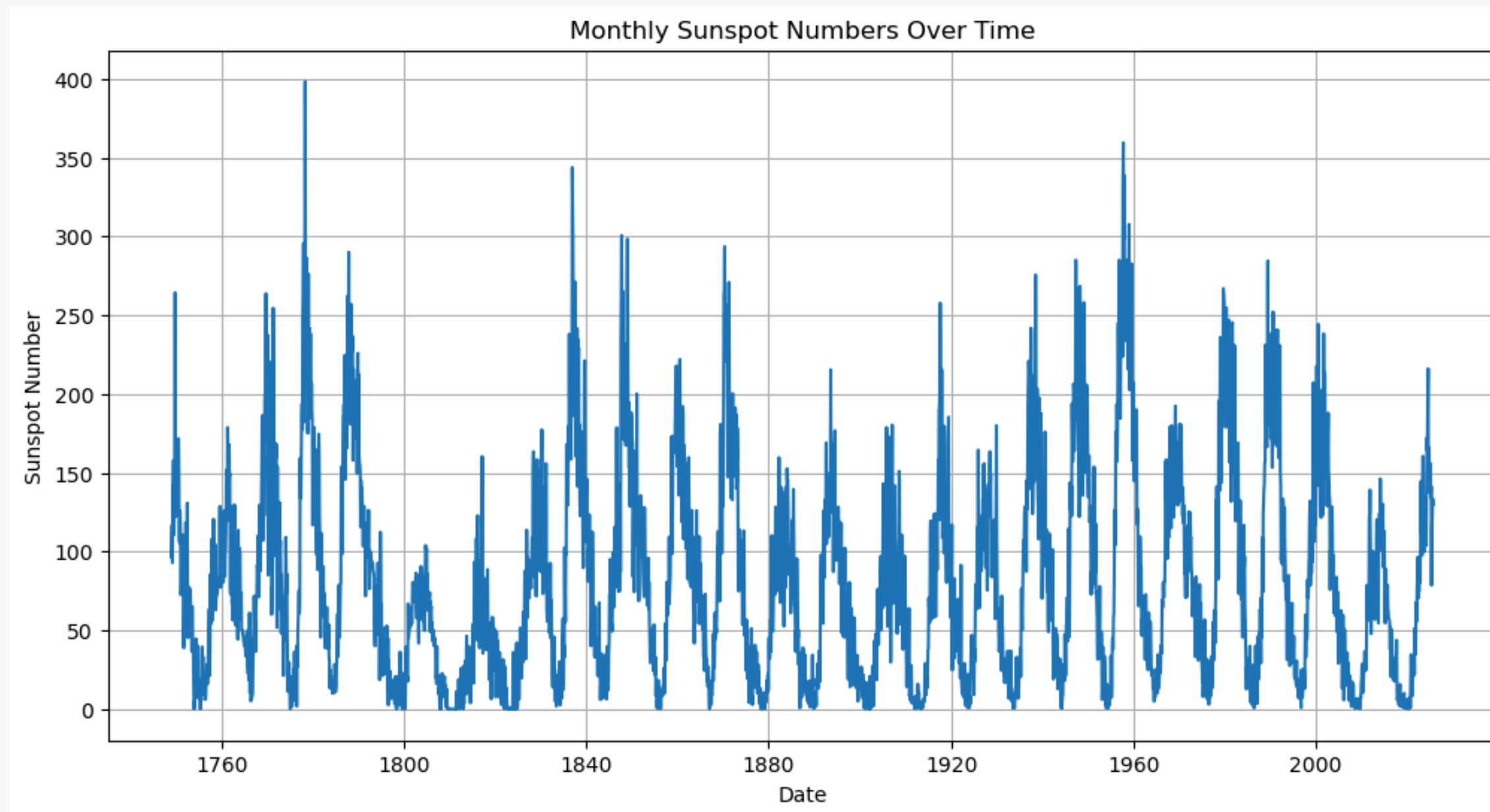
Data structure:
- Date
- SunspotNumber
- 3321

Data characteristics
- Period: 11 years
- Noise: dramatic change
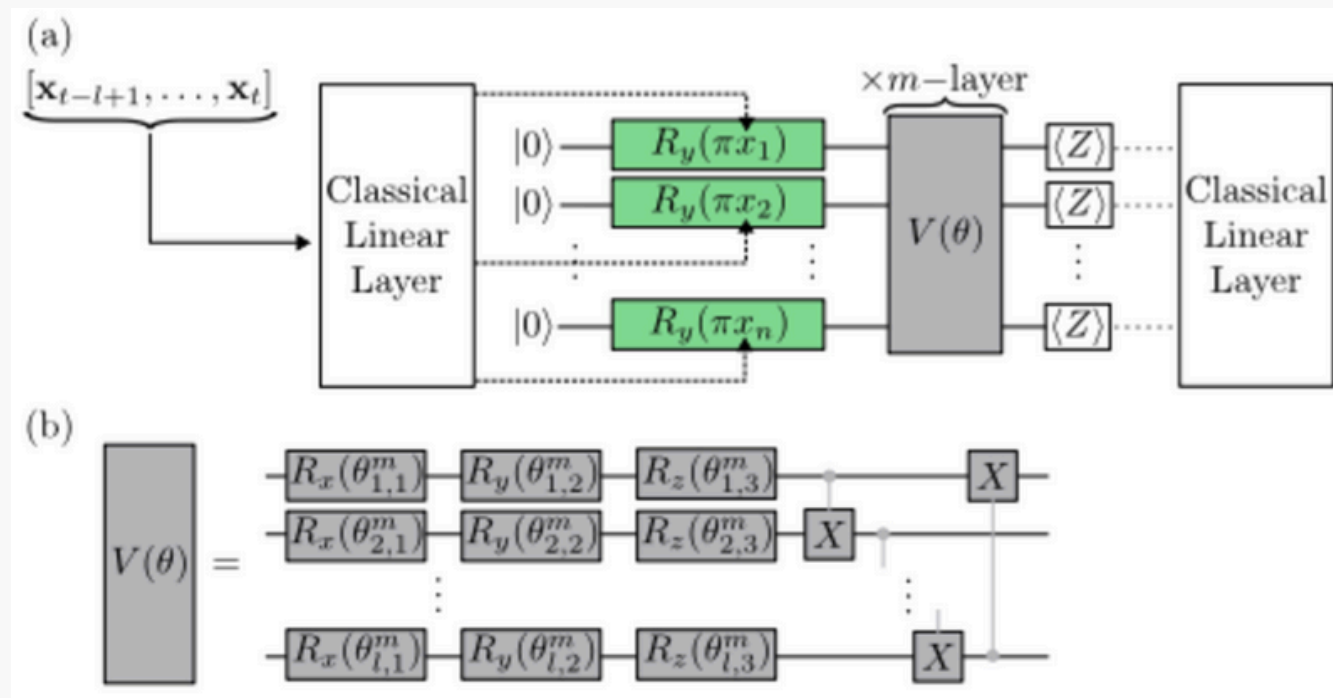- Long-term

Data preprocessing

```
Train shapes: X=torch.Size([2316, 12]), y=torch.Size([2316])
Validation shapes: X=torch.Size([496, 12]), y=torch.Size([496])
Test shapes: X=torch.Size([497, 12]), y=torch.Size([497])
```

- Normalize the data to the range [0, 1]
- seq_length = 12 (sliding window)
- prediction_step = 1
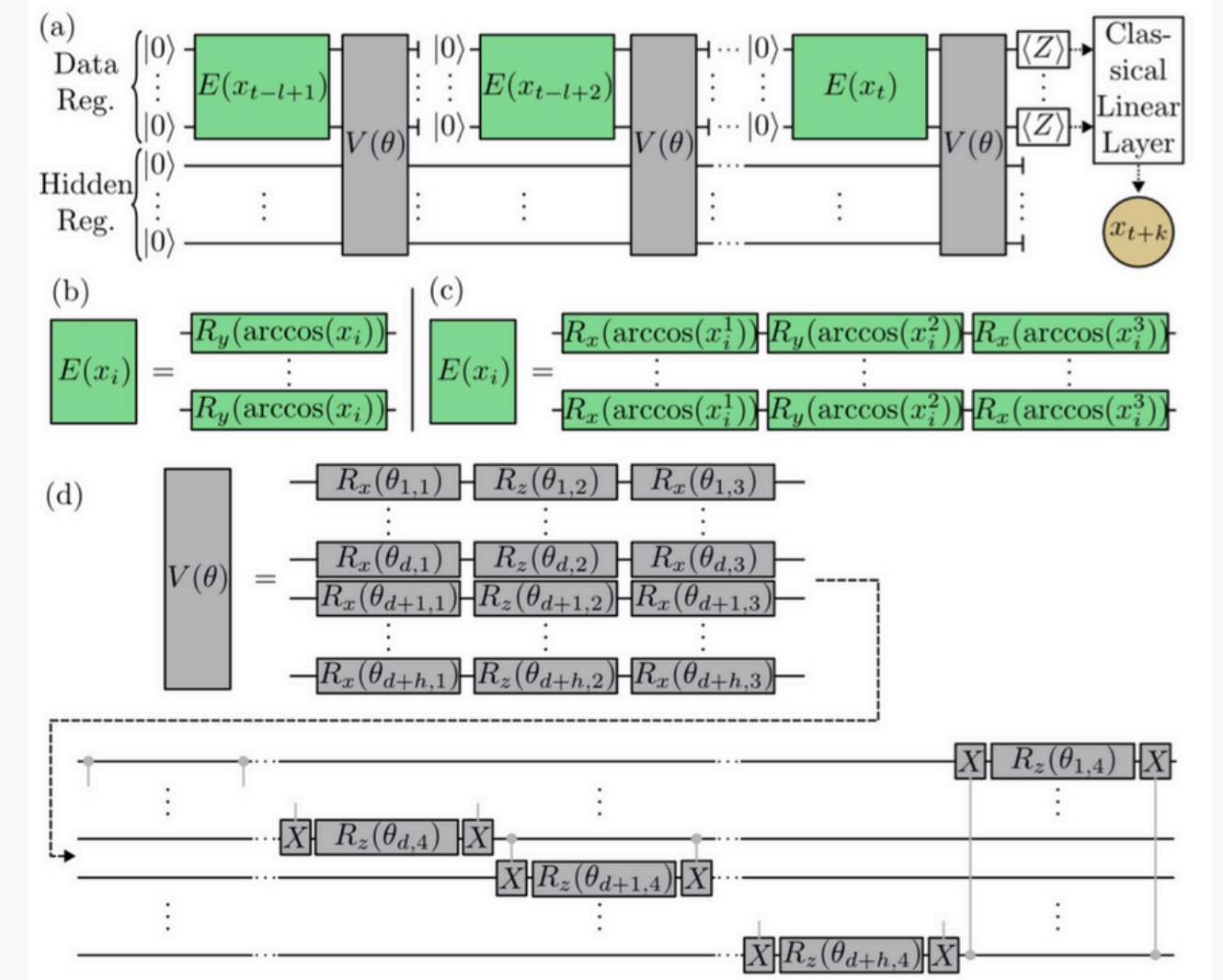- tran/val/test = 70/15/15 (no shuffle)

quantum models

FRAMEWORK PennyLane + PyTorch

D-QNN

- Encoding: RY (pi*x_i)
- Rotation layers: RX-RY-RZ
- Entangling layer: CNOT
- Weights: nqubits*nlayers*3
- Measurement: PauliZ(i) - nqubit
- InputLayer: Linear(seq_length, nqubits)
- OutputLayer: Linear(nqubits, 1)

QRNN

- nqubitdata >= feature, reset
- Encoding: RY(arccos(i))
- Rotation layers: RX-RZ-RX
- Entangling layers: CNOT-RZ-CNOT ~ CRZ
- weights: nqubits*4
- Measurement: PauliZ(i)- nqubitdata

Results

- lr = 0.01
- batch_size = 32
- optimizer: Adam
- criterion: MSELoss
- max epoch: 1000, patience: 50

Mô hình	Train MSE	Val MSE	Test MSE	Gap (Train→Test)
MLP	0.003802	0.004396	**0.002952**	**−0.00085**
RNN	0.004127	0.004430	0.003045	−0.00108
DQNN	0.003933	0.004497	0.003188	−0.00074
QRNN_Reset	0.004145	0.004851	0.003271	−0.00087
QRNN_No_Reset	0.005093	0.006159	0.003862	−0.00123

Model	Train MSE	Val MSE	Test MSE	Test MAE	Early Stop Epoch
DQNN_q2_l1	0.003976	0.004713	**0.002992**	0.039846	55
DQNN_q2_l2	0.003904	0.004660	**0.002908**	0.038290	83
DQNN_q2_l3	0.003929	0.004457	**0.002938**	0.038083	61
DQNN_q4_l1	0.003997	0.004570	0.003062	0.040543	44
DQNN_q4_l2	0.003883	0.004534	0.003029	0.038422	49
DQNN_q4_l3	0.003811	0.004483	0.003027	0.038690	108
DQNN_q6_l1	0.003876	0.004443	0.002957	0.038714	57
DQNN_q6_l2	0.003857	0.004605	0.003031	0.039413	48
DQNN_q6_l3	0.003933	0.004527	0.003041	0.040261	46

Model	Train MSE	Val MSE	Test MSE	Test MAE	Early Stop Epoch
QRNN_q2_reset	0.004533	0.005123	0.003184	0.041062	55
QRNN_q2_no_reset	0.005629	0.008298	0.004659	0.052155	61
QRNN_q4_reset	0.005257	0.007556	0.004420	0.049839	127
QRNN_q4_no_reset	0.004294	0.004806	**0.003186**	0.042959	78
QRNN_q6_reset	0.004539	0.005438	0.003429	0.042170	91
QRNN_q6_no_reset	0.004255	0.004540	**0.003118**	0.041659	191