Understanding Wind Turbine Interactions Using Spatiotemporal Pattern Network (STPN)

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Introduction

- Wind power is a significant alternate source of energy.
- Wind power prediction is difficult due to its stochastic nature and intermittence of wind source.
- The state-of-the-art techniques mostly focus on predicting short-term farm-wide energy production, not capturing various complex spatiotemporal interactions of turbine-turbine or turbine-wind pattern.

Background

➢ **Probabilistic finite state automaton (PFSA):**

- A 4-tuple $K = (\Sigma, Q, \delta, \widetilde{\Pi})$

where Σ is the symbol alphabet, Q is the set of states, δ: Q $\times$ $\Sigma \rightarrow Q$ is the state transition map, $\widetilde{\Pi}$: $Q \times \Sigma \rightarrow [0,1]$ is the symbol generation function.

➢ ***D*-Markov machine**:

- A PFSA in which each state is represented by a finite history of D symbols.
- For a statistically stationary process $S = \cdots s_{-1}s_0s_1\cdots$, $P[s_n|s_{n-1}\cdots s_{n-D}\cdots s_0] = P[s_n|s_{n-1}\cdots s_{n-D}]$.

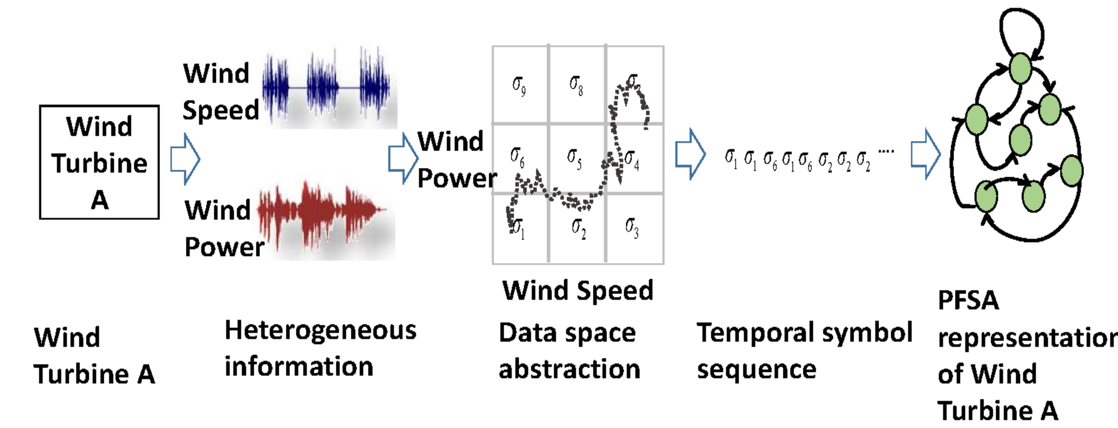
➢ **x*D*-Markov machine**:

- A xD-Markov machine is defined as a 5-tuple that involves two symbol streams represented by $\{s_1\}$ and $\{s_2\}$: $\mathcal{M}_{1\rightarrow 2} \triangleq (Q_1, \Sigma_1, \Sigma_2, \delta_1, \widetilde{\Pi}_{12})$.

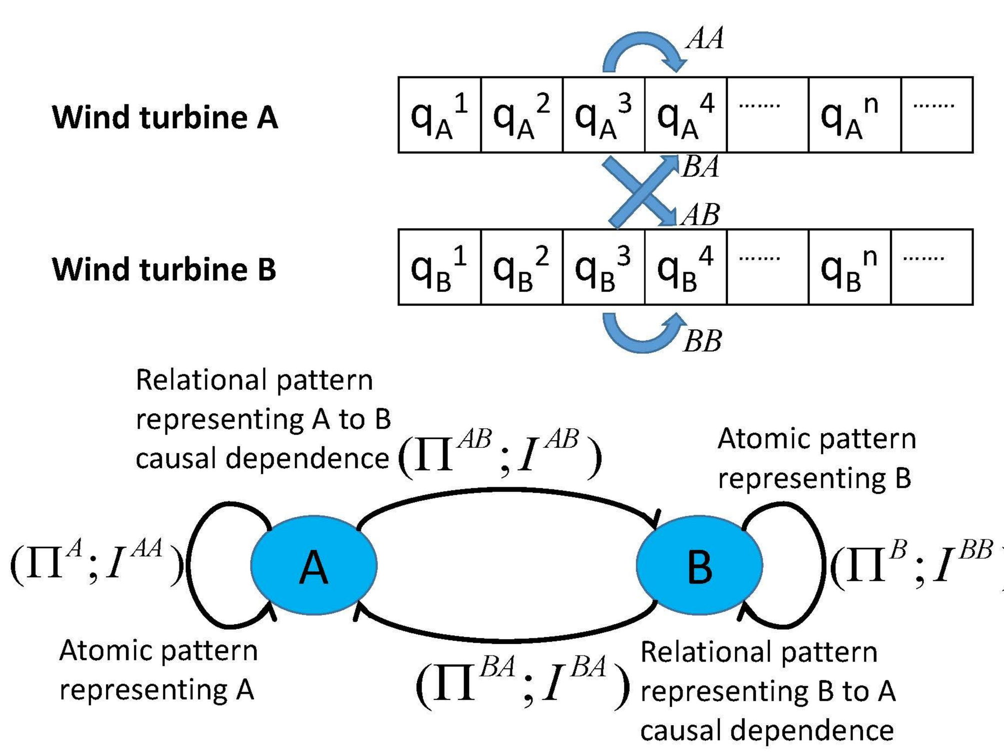
where Q_1 is the state set of symbol sequence $\{s_1\}$, $\widetilde{\Pi}_{12}$ is the symbol generation matrix.

Spatiotemporal Pattern Network

➢ **Symbolic Dynamic Filtering (SDF):**



- Steps of generating a D-Markov machine :
  Data partition → Symbolization → PFSA
- Extraction of **atomic** (D-Markov machine) and **relational** (xD-Markov machine) patterns:



- Cross-state transition matrices Π^{AB} and Π^{BA} are shown as follows:

$$\pi_{kl}^{AB} \triangleq P(q_{n+1}^{B} = l | q_n^A = k)\ \forall n$$
$$\pi_{ij}^{BA} \triangleq P(q_{n+1}^{A} = j | q_n^B = i)\ \forall n$$

- **Mutual information** to quantify the information content in the atomic and relational patterns:

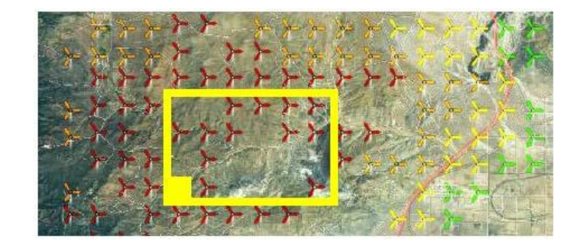
$$I^{AA} = I(q_{n+1}^{A}; q_n^A) = H(q_{n+1}^{A}) - H(q_{n+1}^{A}|q_n^A)$$
$$I^{AB} = I(q_{n+1}^{B}; q_n^A) = H(q_{n+1}^{B}) - H(q_{n+1}^{B}|q_n^A)$$

- Using learnt Markov model in continuous domain to predict wind power:

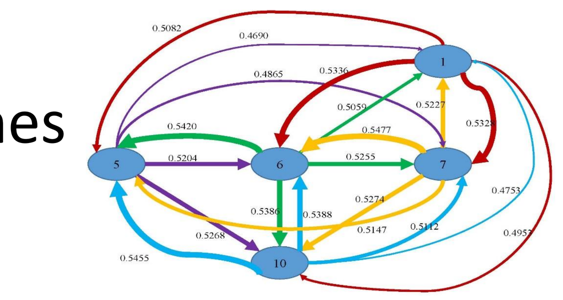
$$E(Power_k) = \sum_{j=1}^{m} Pr_k(j) E(Power|j)$$

Problem Setup

Spatiotemporal interactions of wind turbines:

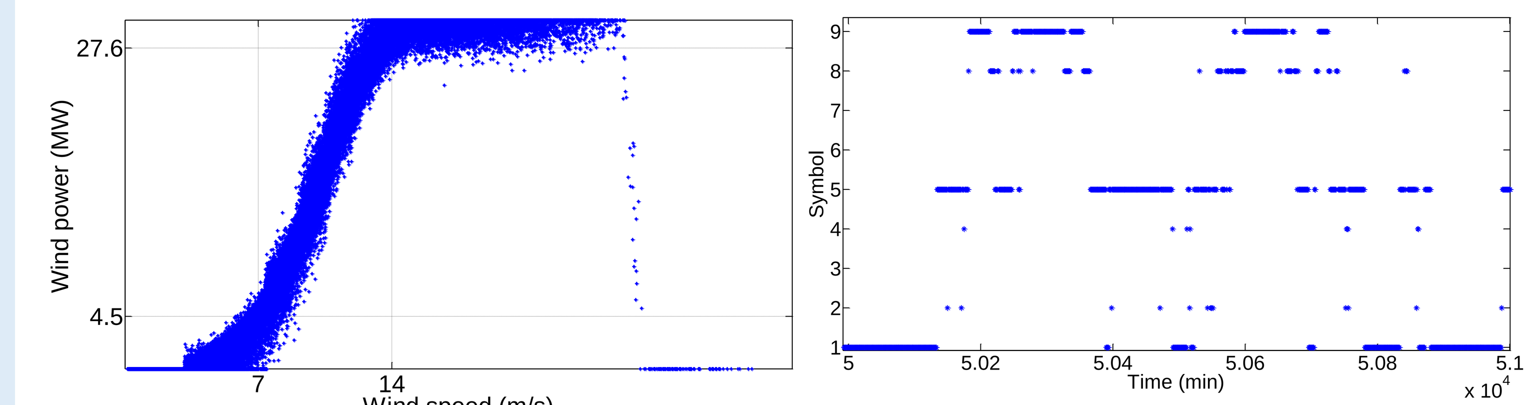


5 wind turbines

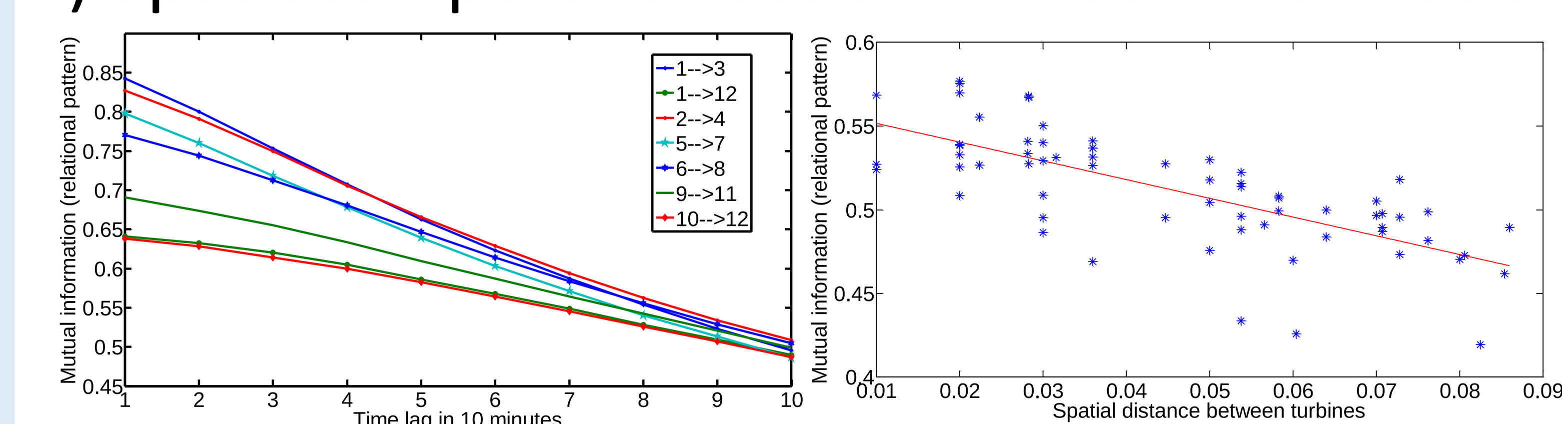


Results

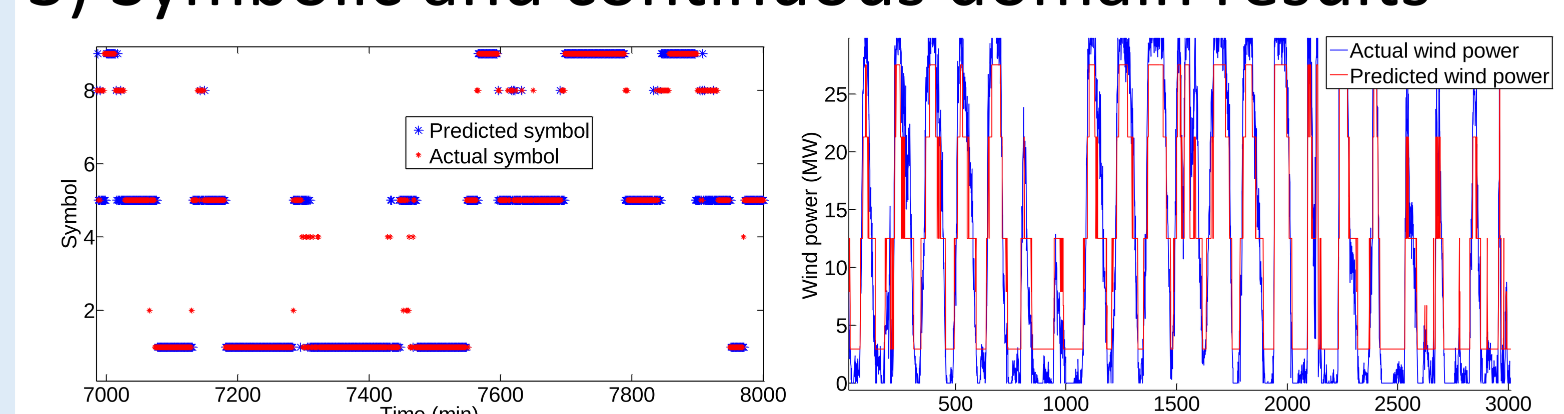
1) Data partition and symbolization



2) Spatiotemporal effect on mutual information



3) Symbolic and continuous domain results



Conclusions

- A novel STPN framework is proposed to capture the interaction characteristics between multiple wind turbines;
- The proposed scheme shows a good predicting ability (validated with real data).

References

Sarkar, S. et al, 2014 "Sensor fusion for fault detection & classification in distributed physical process". Frontiers in Robotics and AI-Sensor Fusion and Machine Perception.