A Cyber-Physical System for PV Monitoring and Control
Cloud Movement and Shading Prediction

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MOTIVATION

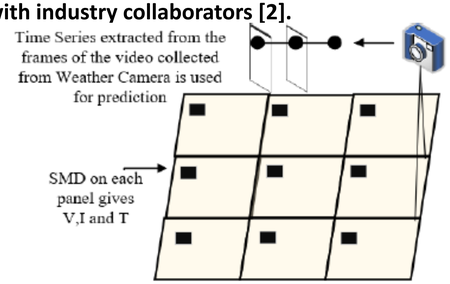
Open problems in PV array management

- **Efficiency improvement in solar energy farms;**
- **Fault detection and power output optimization;**
- **Find correlation between imagery and PV circuit;**
- **Skyline feature prediction for better power grid control.**

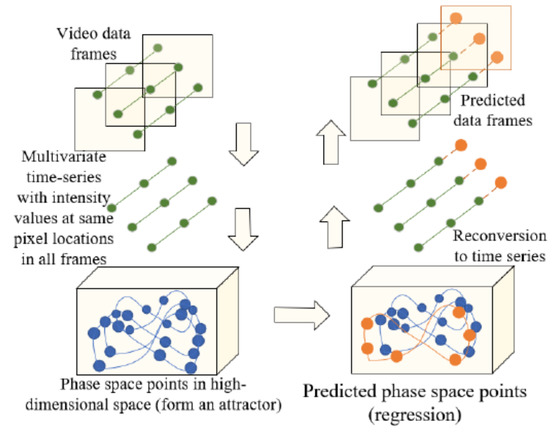
PROJECT AIM

- **Power Output Optimization by skyline feature prediction using imaging algorithms.**
- **Using ML techniques with sensor fusion data from PV modules for fault detection.[1]**
- **Using Topology Optimization based on predicted Shading conditions for maximum power output.**

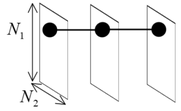
The SenSIP 18kw (104 panel) experimental facility established at ASU with industry collaborators [2].



VIDEO PREDICTION ALGORITHM



MODELING AND PREDICTION



- **I(x, y, t) represents a video.**

$$\boldsymbol{p_t} = [p_{1,t}, p_{2,t}, \ldots . p_{M,t}]^T \in R^M$$
$$\boldsymbol{P} = [\boldsymbol{p_1}, \boldsymbol{p_2}, \ldots . \boldsymbol{p_T}] \in R^{M\ x\ T}$$

- **Phase Space Matrix.**

$\mathbf{E} = [\boldsymbol{e_1}, \boldsymbol{e_2}, \ldots . \boldsymbol{e_N}] \in R^{M\ x\ \sum_{i=1}^{M} d_i}$ **where each** $\boldsymbol{e_t}$ **is a phase space point.**

- **Kernel Regression for Prediction.**

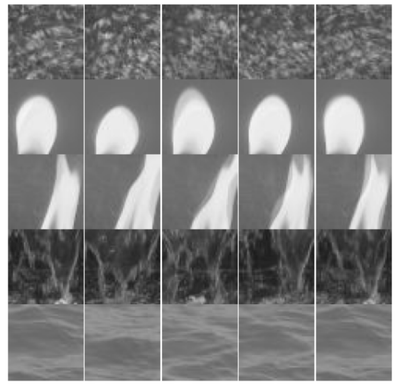
$\boldsymbol{e_{t+1}} = \boldsymbol{F(e_t)} = \sum_{k=1}^{N(e_t)} (\boldsymbol{x_{k+1}} - \boldsymbol{x_k} + \boldsymbol{e_t}) \boldsymbol{w_k(e_t, x_k)}$

where $\boldsymbol{x_k} \in \mathbf{E}$ **is the** $\boldsymbol{k^{th}}$ **nearest neighbor of** $\boldsymbol{e_t}$ **and** $\boldsymbol{w_k(e_t, x_k)}$ **are Nadaraya Watson weights [3,4].**

- **Locality Sensitive Hashing Method is used to improve the computation efficiency compared to Exhaustive Nearest Neighbor Methods [5,6].**

PRELIMINARY RESULTS

- **Predicted Frame Numbers : 100, 250, 400, 550 and 700 (horizontally)**
- **Classes: Boiling Water, Candle, Fire, Fountain, Sea (vertically)**
- **Around 780 frames predicted using 75 frames.**



	K-NN (PSNR)	LSH (PSNR)	K-NN (FSIM)	LSH (FSIM)
Boiling Water	17.57	17.61	0.75	0.746
Candle	13.37	13.33	0.79	0.79
Fire	15.39	15.38	0.777	0.7772
Fountain	18.64	18.66	0.745	0.741
Sea	23.15	23.15	0.767	0.768

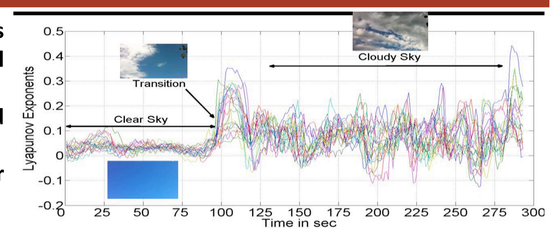
Columns 1 and 2 represent PSNR and Columns 3 and 4 represent FSIM for 75 frames generated by exhaustive K-NN method and LSH with k = 25 respectively.

	K-NN	LSH ($k = 5$)	LSH ($k = 10$)	LSH ($k = 15$)	LSH ($k = 20$)	LSH ($k = 25$)
Boiling Water	511.36	161.69 ±6.77	160.88 ±5.83	139.08 ±6.72	121.73 ±6.67	**115.26 ±7.73**
Candle	497.71	162.04 ±4.83	148.35 ±4.89	116.85 ±6.15	96.99 ±6.07	**97.83 ±6.47**
Fire	548.39	158.18 ±3.51	162.96 ±3.77	142.47 ±5.70	113.70 ±6.02	**103.76 ±5.73**
Fountain	484.48	160.10 ±2.08	154.77 ±4.60	148.71 ±4.99	112.72 ±6.34	**110.57 ±5.45**
Sea	413.18	147.84 ±2.49	149.89 ±3.54	141.90 ±6.34	132.56 ±6.34	**125.65 ±5.63**

Computation Time (in seconds) for 7 Hash Tables. Number of bits (k) = 25 gave the optimal computation time.

ONGOING & PLANNED WORK

- **Develop shading prediction systems using a small network of horizontal viewing cameras.**
- **Weathercam data used in Cloud Movement Prediction.**
- **Sequential Models explored for prediction in phase space.**



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