Missing Sensors Restoration for System Control and Diagnostics

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Issue

- **Monitoring, diagnosis and control of complex drive systems requires measurements that are available and accurate**
  - **Physical quantities such as current, voltage, speed, torque, position, frequency, flux, signal propagation**
  - **Abstract mathematical variables of features**

Problems

- Sensors data, analog or digital, are transmitted to a *control hub* that makes decision.
- **Failures could occur in**
  - **communication links**
  - **routers, switches**
  - **sensors**
- **Sensor data may also be lost due to**
  - **transmission delays**
  - **Noise**
  - **unreliable transmission**

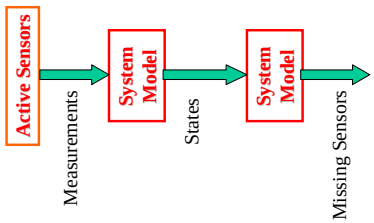
Missing Sensors Restoration (MSR)

- **MSR establishes data dependency among sensors to later restore information of failed sensors.**

Existing Techniques for Reconstruction of Missing Sensors

- State Estimation
- Kalman Filter
- Extended State Estimation
- … … …

State Estimation



State Estimation - Limitations

- *The system model must be available*
  - **Complex structure is approximated**
- *The system model must be elaborate enough to capture all necessary correlations of all sensors and all states*
  - **Nonlinear relationship is often linearized to simplify the computations**
- *The system Topology must be Fixed*
  - **Is not true for dynamically changing system**

State Estimation - Limitations

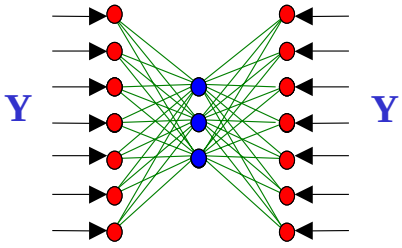
- *The system must be observable*
  - **?**
- *Pseudo-measurements must be introduced*
  - **Often compromise the accuracy of the estimator.**
- *The quality of the data must be high.*
  - **noise or other uncertainties degrades the estimation accuracy**

Missing Sensors Restoration (MSR)

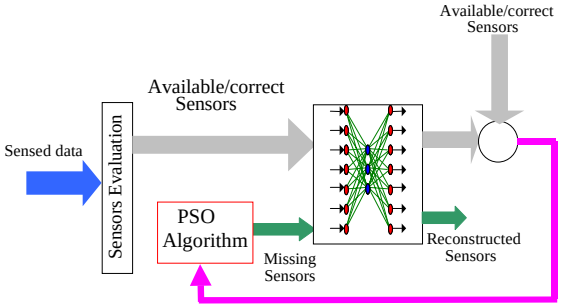
- **Two step process:**

1. **Develop an encoder to capture the dependency among sensors**
2. **Use fast search technique and the encoder to restore the data of the missing sensor.**

MSR: NN Encoder

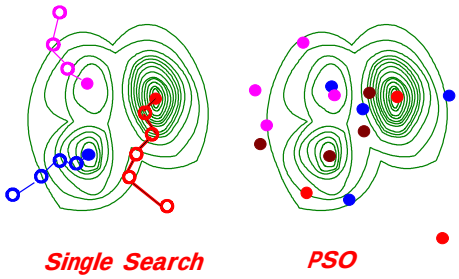


MSR: Data Reconstruction



Particle Swarm Optimization Search

PSO vs SST



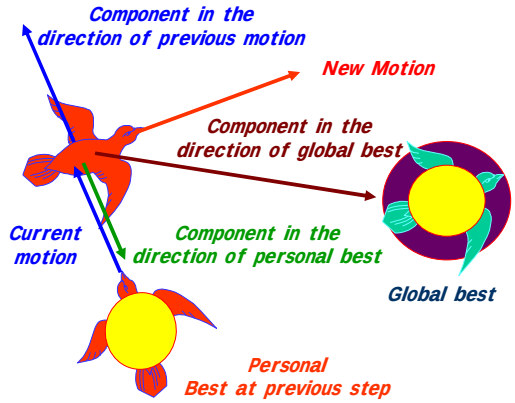
Single Search PSO

Particle Swarm Optimization

- ***Inventors:*** James Kennedy and Russell Eberhart
- An Algorithm originally developed to imitate the motion of a Flock of Birds, or insects
- Assumes Information Exchange (Social Interactions) among the search agents
- Basic Idea: Keep track of
  - Global Best
  - Self Best

How does it work?

- Problem:
  Find $\boldsymbol{X}$ which minimizes f($\boldsymbol{X}$)
- Particle Swarm:
  - ***Start:*** Random set of solution vectors
  - ***Experiment:*** Include randomness in the choice of new states.
  - ***Remember:*** Encode the information about good solutions.
  - ***Improvise:*** Use the 'experience' information to initiate search in a new regions



Particle Swarm Dynamics

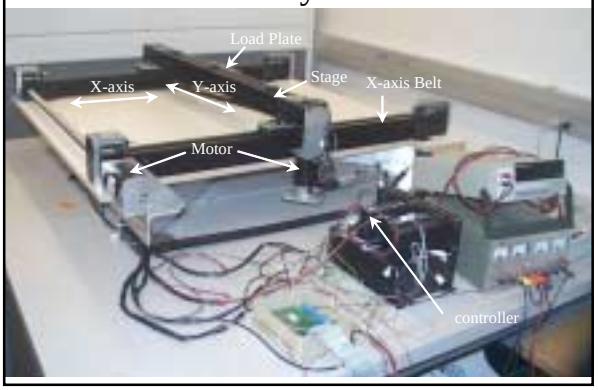
$$\vec{x}(k+1) = \vec{x}(k) + \vec{v}(k)$$

non-zero velocity
PS never stop flying

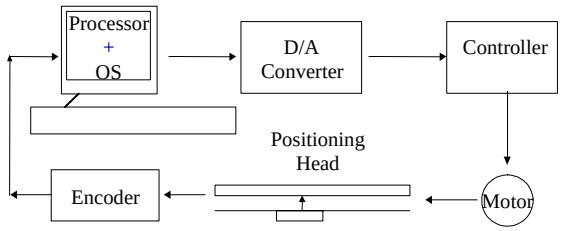
$$\vec{v}(k+1) = w.\vec{v}(k) + r(0,a_1).(\vec{x}_{SelfBest}(k) - \vec{x}(k)) + r(0,a_2).(\vec{x}_{GroupBest}(k) - \vec{x}(k))$$

Inertia
Self consciousness of the swarm
Controlled randomness
The collective consciousness of the swarm

Test System



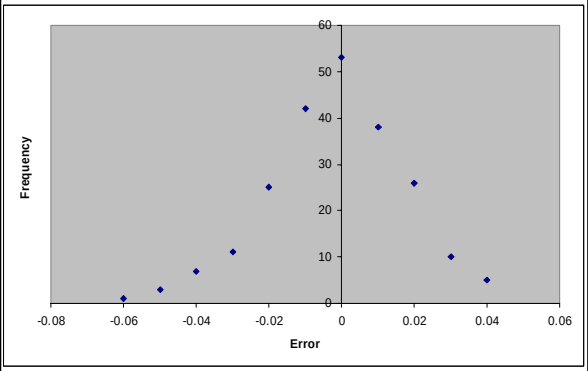
Test System



Test Conditions

- Measurements:
  - Voltage, current, speed, torque, stage position, reference and carrier frequencies.
- Several loading and operating conditions were used.
- Each of the measurements was assumed missing and is predicted by the MSR

Test result



Conclusions

- MSR is an effective method.
- Applied to
  - Airplane engine vibration
  - Power system vulnerability monitoring
  - Chemical process
  - Drives and control
- Need to be tested in more complex drives environment where ambient and electrical conditions are sensed.