Neural Network Data Representation and Processing for Sensor Arrays

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Acknowledgements

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Desirable Characteristics of MEMS Sensor Array Signal Processing

➔improved sensor accuracy

– reduce effects of individual sensor noise

– accomodate sensor-to-sensor variation

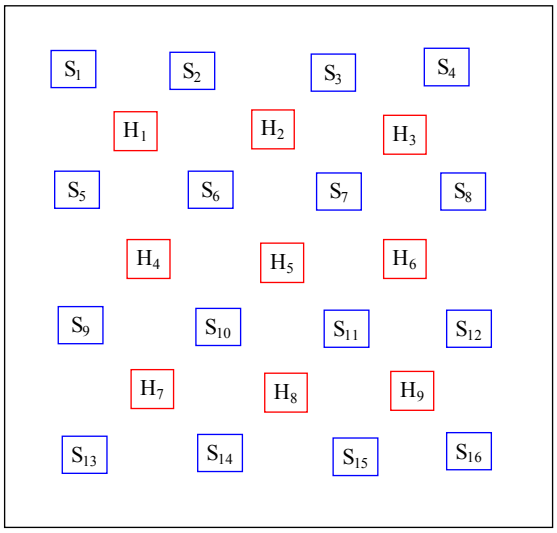
➔automatic compensation for sensor drift and failure

➔perform data compression

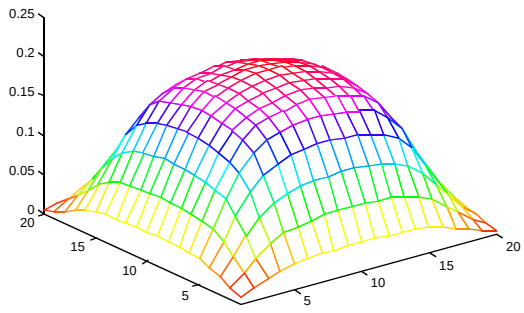
➔multi-sensor fusion

Integrated Heater/Sensor Simulation

➔ Heater/Sensor configuration

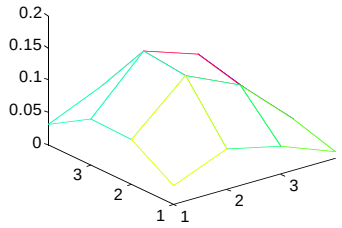


➔ Regular Pattern without Heater Failure

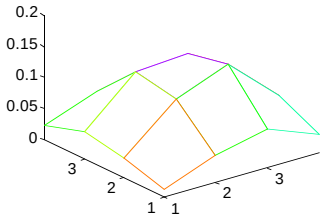


Heater Failure Patterns

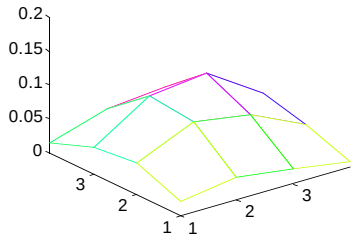
Heater 3,5 failure



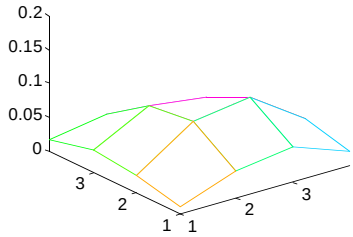
Heater 1,4,8 failure



Heater 2,3,5,6 failure



Heater 1,3,7,8,9 failure



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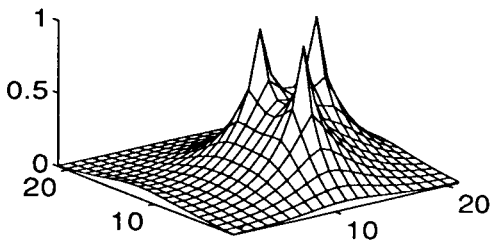
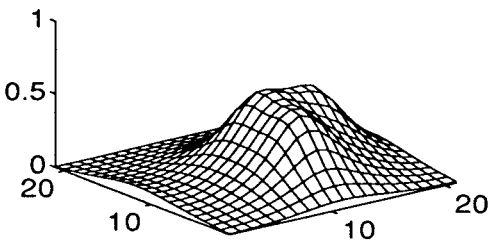
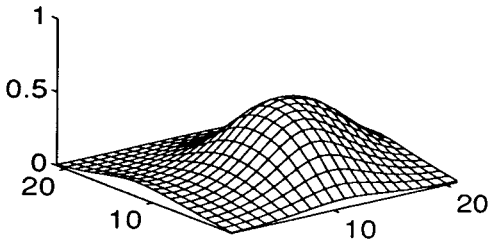
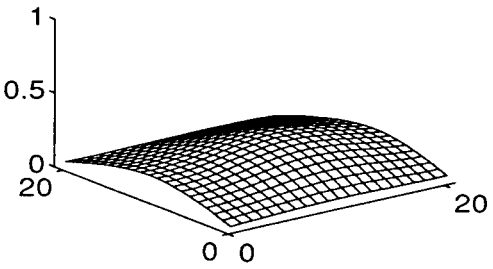
Simulated heating/cooling profiles









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Sensor Array Calibration using a Neural Net

Objective

➔ to achieve the behavior of a precise sensor with an array of lower resolution sensors after calibration of the array against the precise sensor.

Possible because of the batch fabrication nature of MEMS technology used in conjunction with neural networks

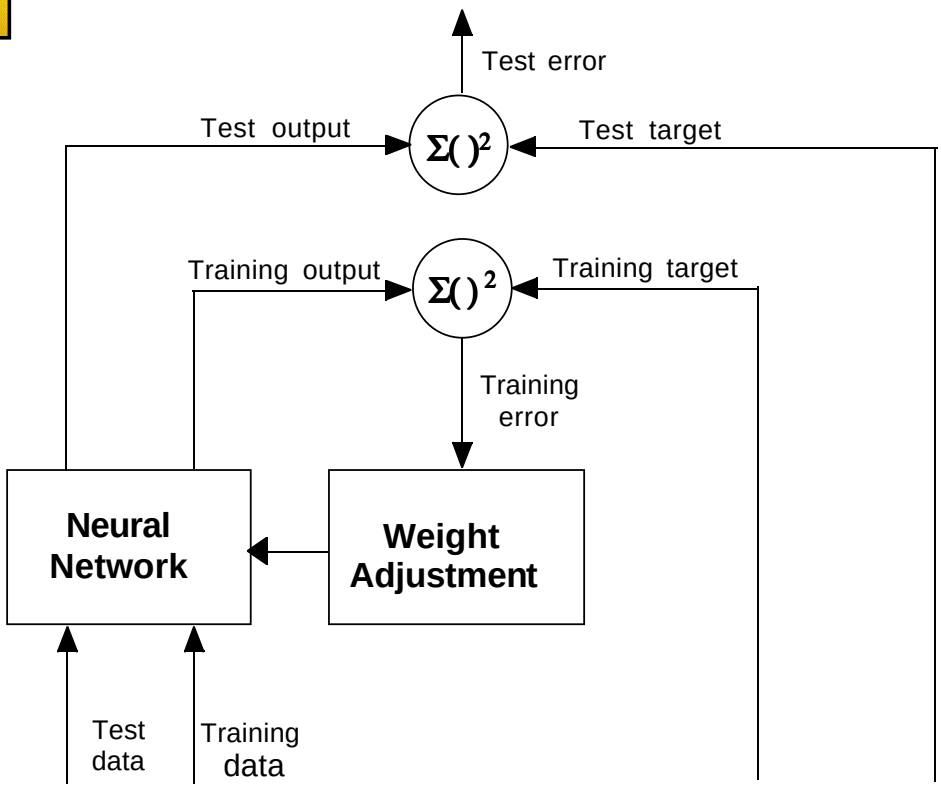
Neural Network

- ➔ Neural Network is a non-linear network which can be used to estimate a functional (input-output) relationship by training the network with the function's values at known points (training phase)
- ➔ The trained network can then be used to estimate the function at other points not included in the training set (generalization or testing phase).
- ➔ The sensor array calibration algorithm is to:

  Train a neural network to learn the relationship between the sensor array's outputs and a precisely calibrated reference sensor. Stop when the training error reaches a threshold such as 10^{-6}.

  Test the neural network's output against the reference sensor for a second set of data.

Training Procedure



Experiments

- ACCELERATION: Shake table housing one precise acceleration sensor and driving a PC board containing 6 ADXL50 accelerometers. Data is obtained as a function of vibration amplitude at a fixed vibration frequency.
- TEMPERATURE: Deionized water bath containing one precision thermistor and 7 low low-cost thermistors. Data obtained as water bath is subjected to a temperature ramp.
- TEMPERATURE: Integrated circuit containing three resistor arrays and a signal multiplexer. Data is obtained in a temperature controlled chamber.

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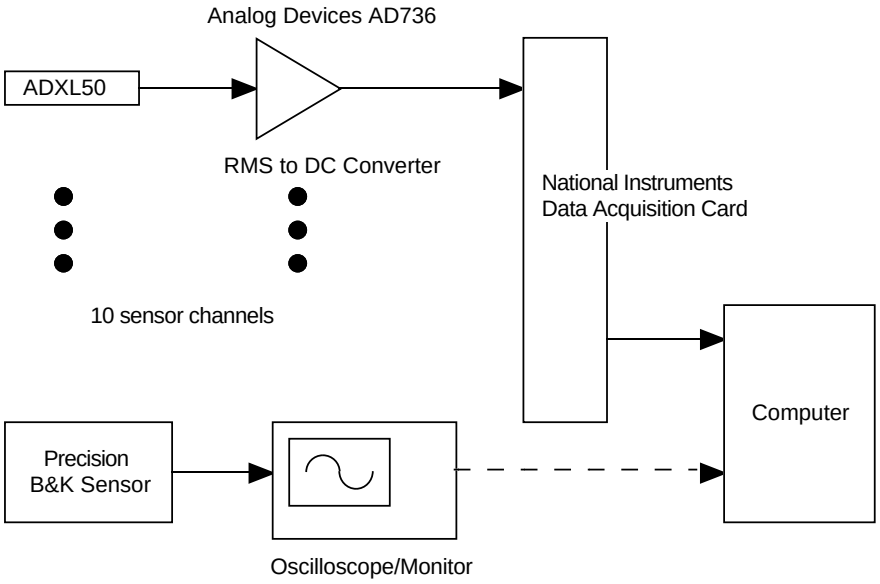
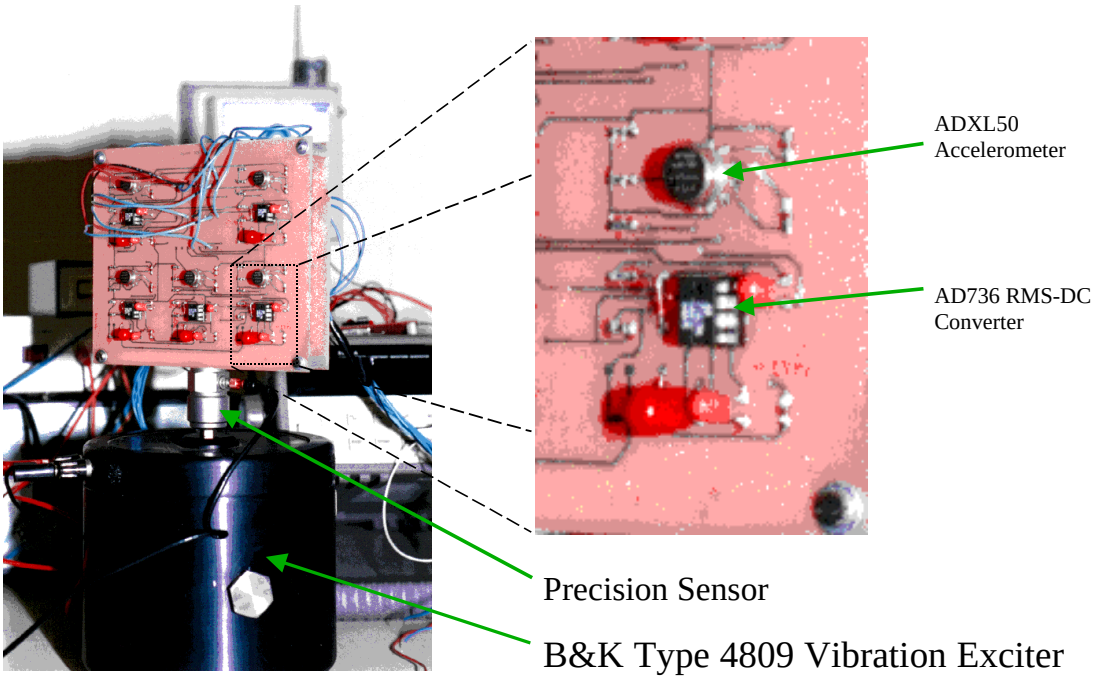
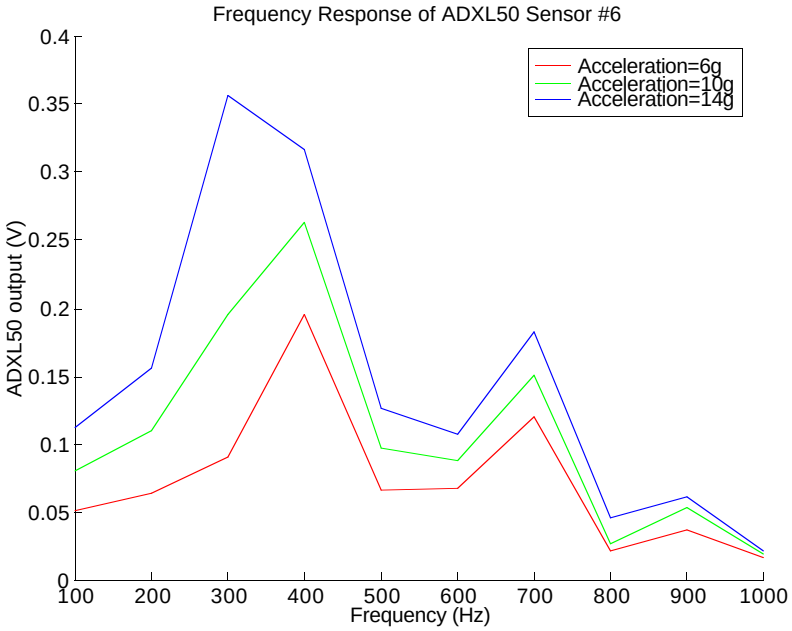
Accelerometer Signal Conditioning



Accelerometer Sensor Array



Test Stand Accelerometer Array Frequency Response



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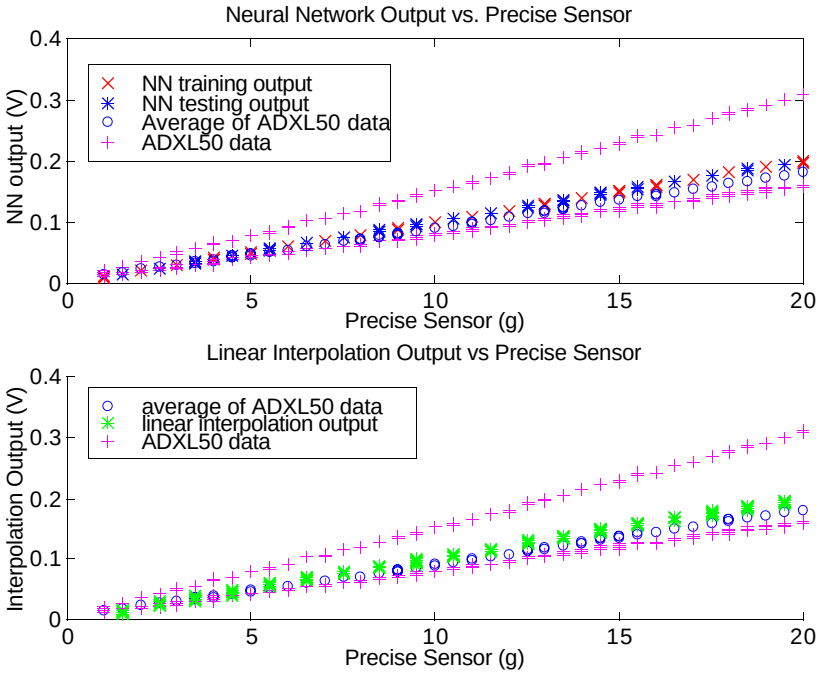
Performance of ADXL sensors



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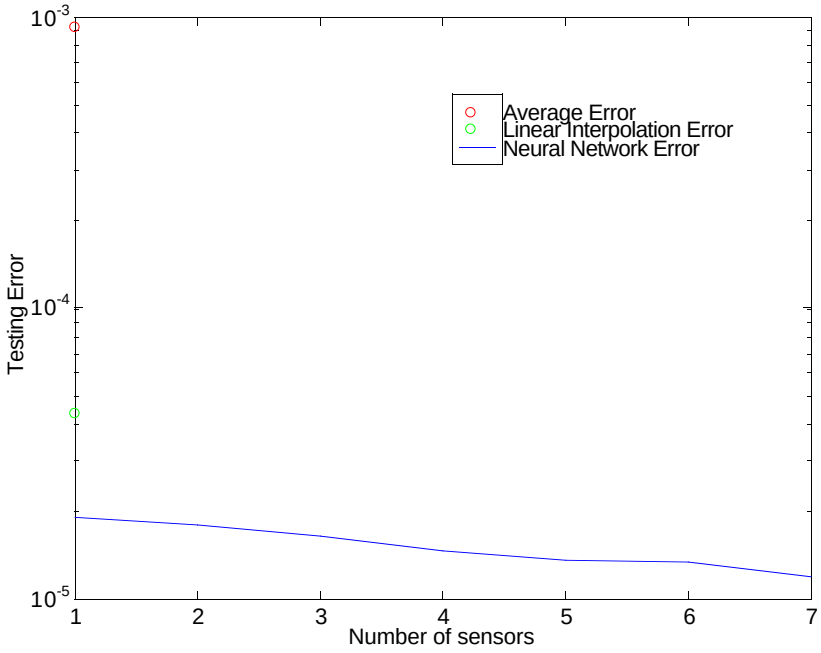
Performance of NN Sensor Array



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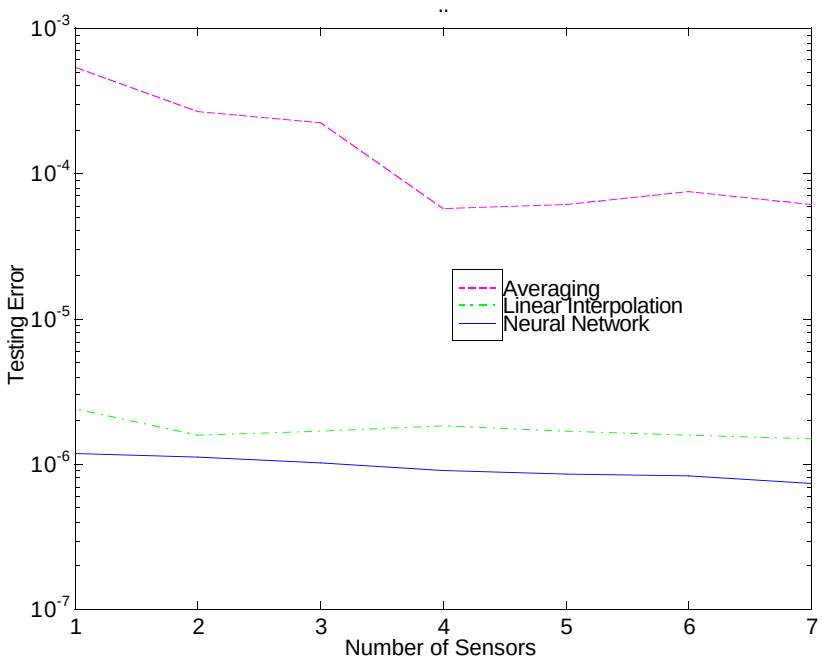
Performance of NN Sensor Array



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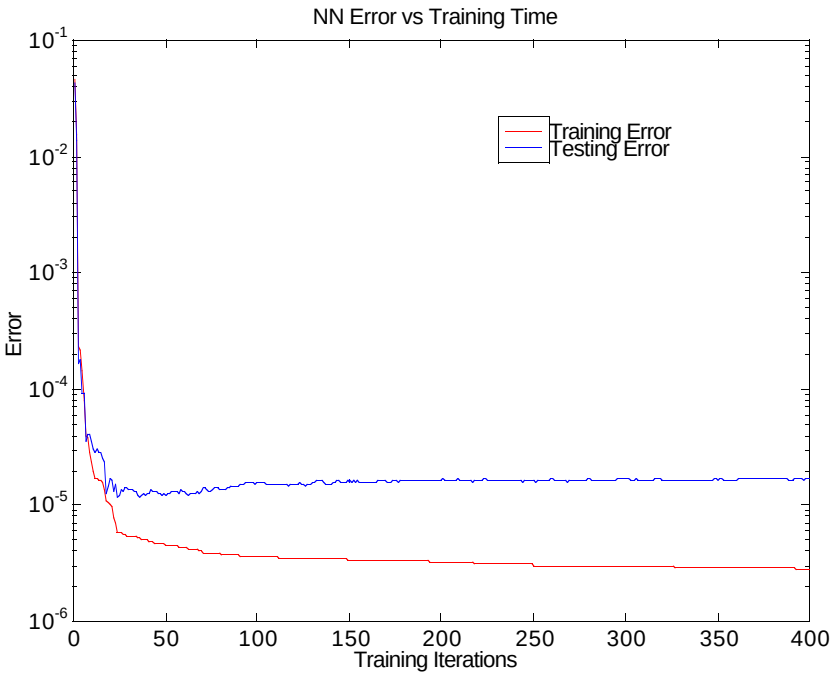
Neural Network Training Error



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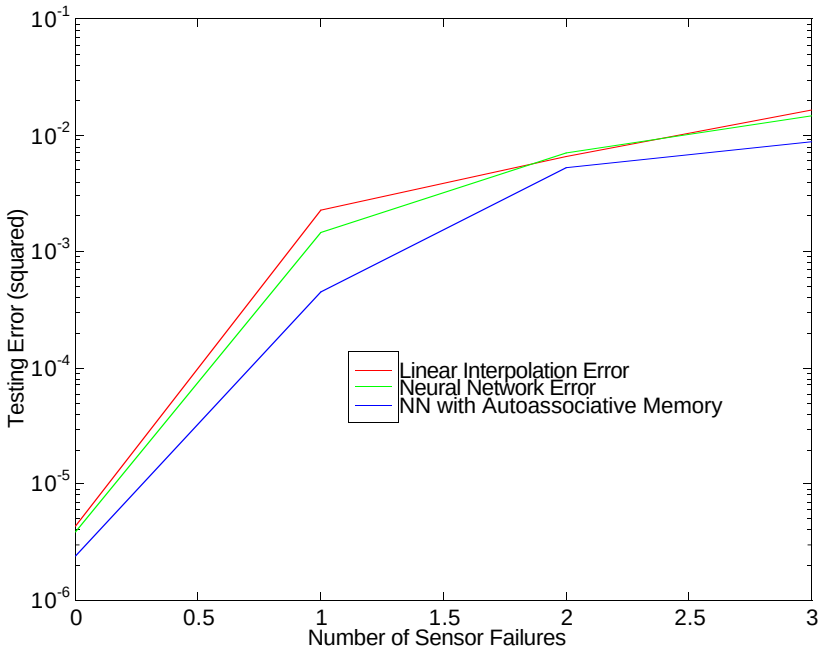
Sensor Failure



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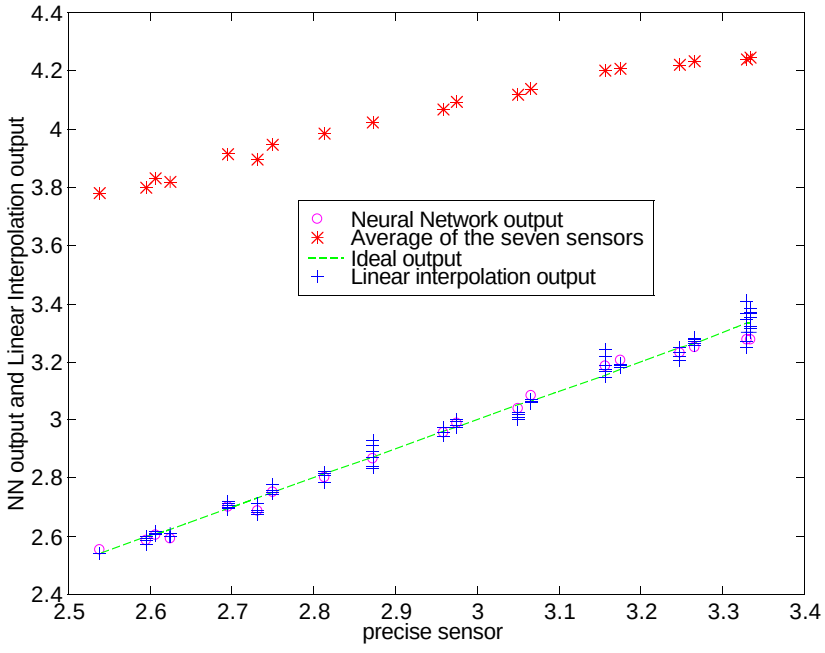
Discussion

Sensor performance is improved:

- ➔ Individual sensor behavior should be repeatable.
- ➔ After a certain period of training, the output error tends to reach a plateau.
- ➔ Error decreases slowly with N, the number of sensors.
- ➔ many identical sensors are used to measure the ***same*** physical quantity

Temperature Sensing (Thermistor) Array



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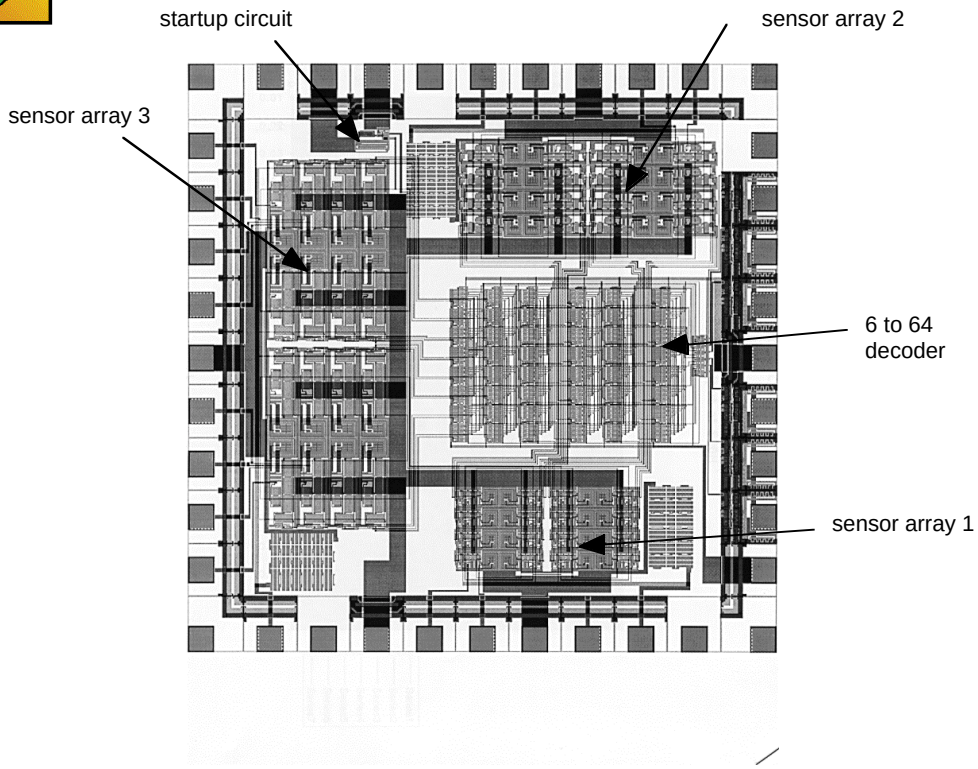
Temperature Sensing (Thermistor) Array

- ➔ Deionized water bath containing one precision thermistor and 7 low low-cost thermistors. Data obtained as water bath is subjected to a temperature ramp.
- ➔ Neural network and linear interpolation handle thermistor non-linearity very well

Temperature sensor chip description

- ➔ Three arrays of 16 sensors each
- ➔ Operational principle: temperature dependence of two bipolar junction transistors (BJT) with 1:10 area ratio.
- ➔ Different sized sensors will have different fabrication accuracies and noise characteristics

Temperature sensor chip



Temperature sensor chip description

➔three sensor arrays consisting of 16 sensors each

➔sensors differ in size with those in array three the largest while those in array one are the smallest

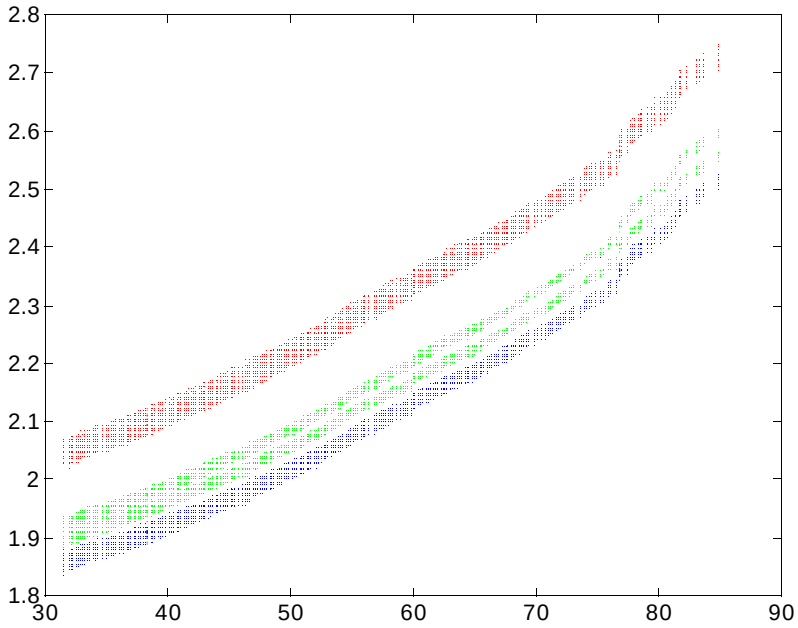
➔digital decoder is used to select one of the 48 sensors with data being collected from the output port

Motivation:

➔the larger the size of the sensor, the smaller the relative error for that sensor due to fabrication tolerances

➔use the large sensor as a precise sensor for the calibration of an array of smaller sensors

Data from Temperature Sensor IC



Discussion

➔inexpensive MEMS arrays for sensing and condition monitoring

➔neural network processing of sensor arrays

- improved calibration techniques for non-linear sensors
- neural network can filter out sensor-to-sensor variations for mass produced sensors.

➔MEMS well matched to neural network processing

Planned Work

➔continue spatial and temporal calibration

➔vector sensing using 2-D/3-D sensor arrays

➔calibration and signal processing techniques for heterogenerous sensors, e.g., different sizes with different time responses

➔“precalibrated” sensor arrays using autoassociative memory

Functional Link Net

➔ Functional link net is a type of neural net with Gaussians as basic transform functions.

➔ The output of the net is the sum of a bias and the individual Gaussian function outputs multiplied by their corresponding weights.

➔ To minimize the error at training points, the weight and bias are adjusted.

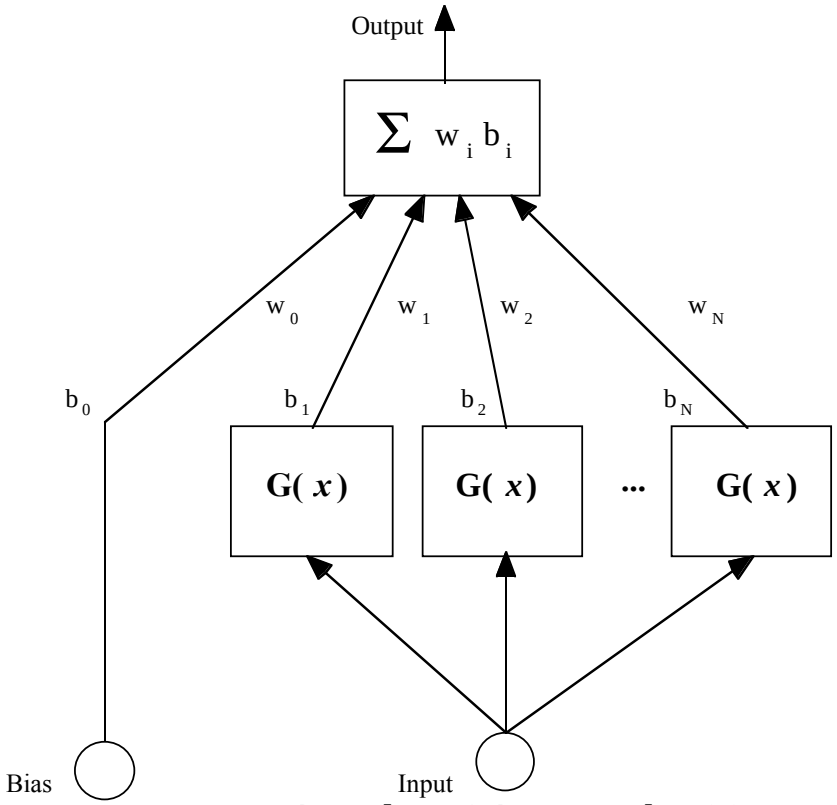
$$\text{Output},j = \text{bias} + \sum(Wi \times bi) \qquad i=1,2,...,n$$

bi — output of each Gaussian function

Wi — weight corresponding to each Gaussian function

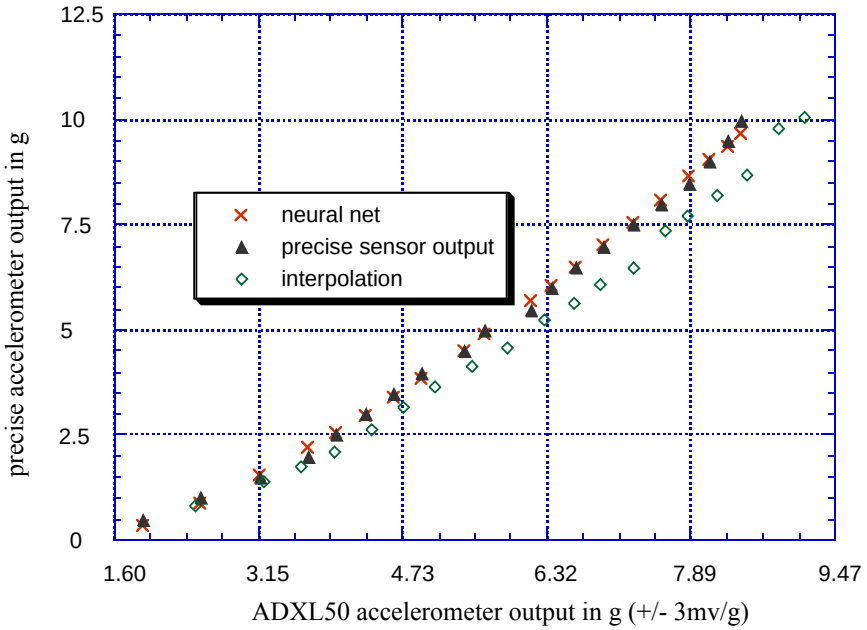
$$\text{Error} = \sum(\text{Output},j - \text{training data})^2, \quad j = 1, 2,...,m$$

Functional Link Net



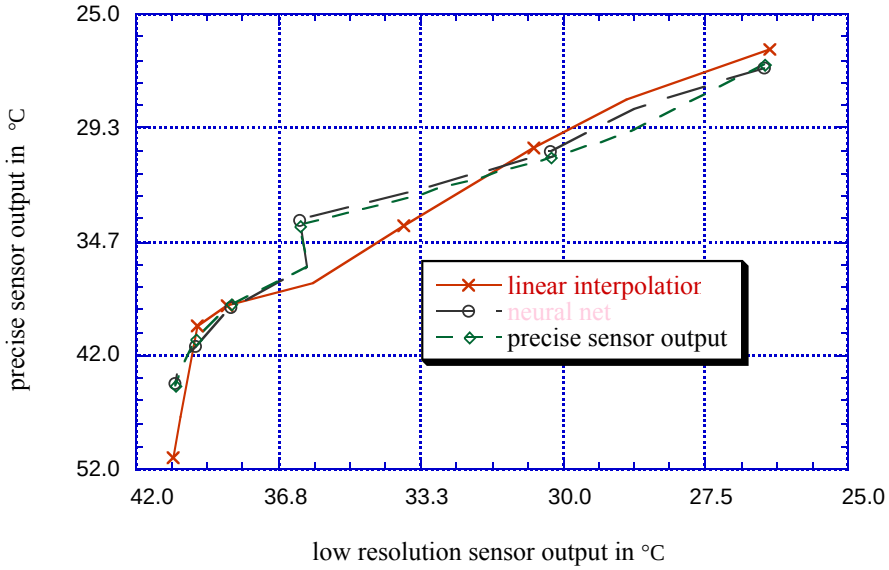
Neural Net versus Linear Interpolation

acceleration sensor data

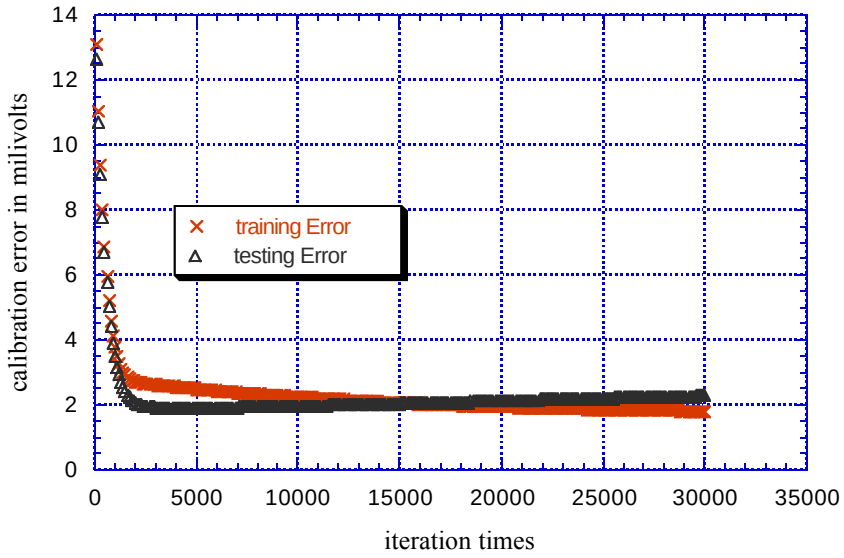


Neural Net versus Linear Interpolation

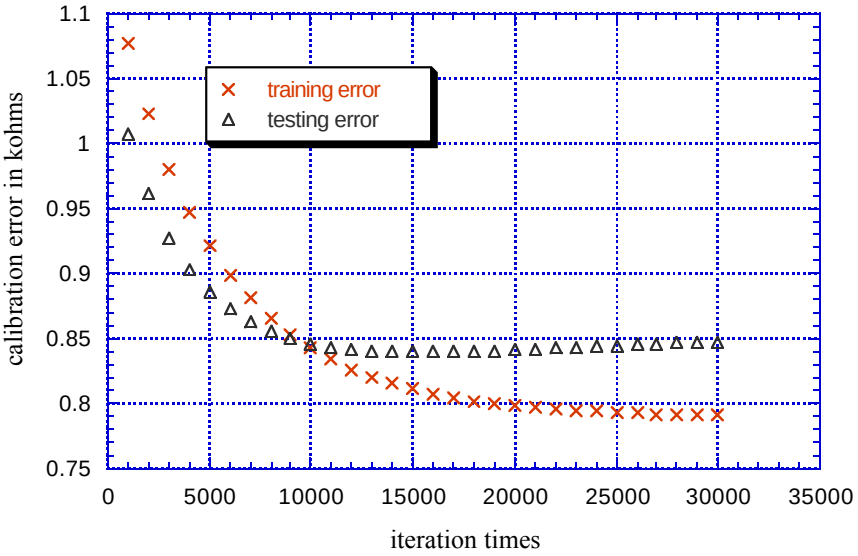
temperature sensor data



Calibration Error of Accelerometer Array



Calibration Error of Temperature Sensor Array



Neural Network Processing of Sensor Array Data

- plot of testing error for linear combination and neural network versus number of sensors