MOTIVATION

- To estimate axial and spindle load in a Computer Numerical Control machine from input sensor readings like spindle speed, feed rate, surface speed etc. – a standard regression problem.
- To develop a data driven approach for load estimation as an alternative to physics based models, which is not always feasible due to complicated manufacturing systems dynamics.
- To learn arbitrary relationships between the load and sensor readings.

PROPOSED APPROACH

- Incorporated a regression model based on the Stacked Autoencoder framework with joint learning of encoder-decoder and regression weights in a more optimal fashion, instead of greedy layer wise training in two phases.
- Regression model built on top of an asymmetric autoencoder architecture to reduce overfitting.
- Formulated a joint optimization problem and solved it using a variable splitting Augmented Lagrangian approach.

Methodology

Step 1: Proposed regression model is formulated as non-convex joint optimization function,

\[
\text{arg min}_{w_1, w_2, w, \lambda} \left\{ \frac{1}{2} \| X - W_D \varphi(W_{E_2} \varphi(W_{E_1} X)) \|_F^2 + \lambda \left( \| y - W^T \varphi(W_{E_2} \varphi(W_{E_1} X)) \|_F^2 \right) \right\},
\]

(1)

Step 2: Two proxy variables are introduced:

\[ Z_2 = \varphi(W_{E_2} \varphi(W_{E_1} X)) \quad \text{and} \quad Z_1 = \varphi(W_{E_1} X) \]

and the eq 1 is reformulated into corresponding Augmented Lagrangian formulation:

\[
\text{arg min}_{w_1, w_2, w, \lambda, z_1, z_2} \left\{ \frac{1}{2} \| X - W_D z_2 \|_F^2 + \lambda \left( \| y - W^T z_2 \|_F^2 \right) + \mu_1 \left\| Z_1 - \varphi(W_{E_1} X) \|_F^2 \right\}
\]

(2)

EXPERIMENTS AND RESULTS

A CNC turning machine

Parameter values considered for experiments using the proposed regression model

<table>
<thead>
<tr>
<th>Axes names</th>
<th>( \lambda )</th>
<th>( \mu_1 )</th>
<th>( \mu_2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Axis 1</td>
<td>1.6</td>
<td>1.3</td>
<td>1.3</td>
</tr>
<tr>
<td>Axis 2</td>
<td>0.5</td>
<td>1.7</td>
<td>1.7</td>
</tr>
<tr>
<td>Axis 3</td>
<td>0.6</td>
<td>1.6</td>
<td>1.6</td>
</tr>
<tr>
<td>Axis 4</td>
<td>1.1</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>Spindle</td>
<td>0.7</td>
<td>1.6</td>
<td>1.6</td>
</tr>
</tbody>
</table>

Performance metrics:

\[
\text{NME} = \frac{\| y - \hat{y} \|_2}{\| y \|_2}
\]

\[
\text{RMSE} = \sqrt{\frac{\sum_{n=1}^{N} (y_n - \hat{y}_n)^2}{N}}; \quad N = \text{length}(y)
\]

MACHINES AND LOAD ESTIMATION VIA STACKED AUTOENCODER REGRESSION

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REFERENCES


Observations

- Consistent improvement in performance compared to other techniques.
- Signal peaks could be better estimated using the proposed model.
- The model can be used for any regression problem.