**Accelerating Eigen* Math Library for Automated Driving Workloads**

**Steena Monteiro**
*Automated Driving Engineering, Software & Services Group*
*Intel Corporation, Santa Clara, California*
Steena.Monteiro@intel.com

**Gaurav Bansal**
*Automated Driving Engineering, Software & Services Group*
*Intel Corporation, Hillsboro, Oregon*
Gaurav2.Bansal@intel.com

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**Small Matrix-Matrix Multiplication in Automated Driving Workloads—Extended Kalman Filter**

Popular automated-driving workloads such as Extended Kalman Filter (EKF) comprise several small DGEMM operations.

EKF fuses RADAR- and LIDAR- sensor data and localizes tracked objects.

**Measurement update**

\[ y = z - H' \cdot x \]

\[ S = H' \cdot P' \cdot H + R \]

\[ K = P' \cdot H' \cdot S^{-1} \]

\[ x = x' + K \cdot y \]

\[ P = (I - K \cdot H) \cdot P' \]

**Prediction**

\[ X' = F' \cdot x + u \]

\[ P' = F' \cdot P' \cdot F' + Q \]

EKF comprises two stages:

**Prediction**

\[ X' = F' \cdot x + u \]

\[ P' = F' \cdot P' \cdot F' + Q \]

**Measurement update**

\[ y = z - H' \cdot x \]

\[ S = H' \cdot P' \cdot H + R \]

\[ K = P' \cdot H' \cdot S^{-1} \]

\[ x = x' + K \cdot y \]

\[ P = (I - K \cdot H) \cdot P' \]

EKF operates on matrices with specific dimensions:

<table>
<thead>
<tr>
<th>Matrix</th>
<th>rows</th>
<th>columns</th>
<th>Matrix</th>
<th>rows</th>
<th>columns</th>
</tr>
</thead>
<tbody>
<tr>
<td>x</td>
<td>4</td>
<td>1</td>
<td>F</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>R</td>
<td>2 or 3</td>
<td>2 or 3</td>
<td>H</td>
<td>2 or 3</td>
<td>4</td>
</tr>
</tbody>
</table>

Automated-driving community typically uses Eigen*, a C++ math library, for DGEMMs on small matrices.

We benchmark DGEMM using Eigen, Eigen with Intel® Math Kernel Library (Intel® MKL), and Eigen with LIBXSMM* with the GNU compiler (g++) and Intel® C++ compiler (icpc) on Intel® Xeon® Gold 6148 CPU @ 2.40GHz. We accelerate EKF that uses native Eigen in its implementation by using Intel® MKL and LIBXSMM through Eigen.

All experiments are in serial. Compiler and library versions: Intel® MKL: MKL 2017 Update 3; Intel® C++ compiler: 17.0.4 20170411; G++:7.2; Eigen: 3.3.3

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**Best DGEMM Variant per Matrix Dimension**

**Accelerating the Extended Kalman Filter**

<table>
<thead>
<tr>
<th>Matrix dimensions (M=N=K)</th>
<th>Eigen + MKL (g++)</th>
<th>Eigen + MKL (icpc)</th>
<th>Eigen + LIBXSMM (g++)</th>
<th>Eigen + LIBXSMM (icpc)</th>
</tr>
</thead>
<tbody>
<tr>
<td>M,N,K &lt;= 13</td>
<td>~2x</td>
<td>~2x</td>
<td>~2x</td>
<td>~2x</td>
</tr>
<tr>
<td>M,N,K &gt; 13</td>
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