Sensor Sensibility: Magnetic Sensors and the Real World

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President & CEO, PNI Sensor Corporation
About PNI Sensor Corporation

PNI Sensor is a leader in magnetic sensor technologies and sensor fusion algorithms with unparalleled expertise in harnessing and fusing data from Earth’s magnetic fields into useful military, scientific and consumer applications.
Two Key Topics

1. 9-axis sensor fusion

2. Aren’t all magnetic sensors pretty much the same?
What is motion tracking?

Tracking a moving object through space

- Up & down
- Side to side
- Back & forth
- How fast
- Where is it facing/pointing
- How is it turning
- Relative to what
What is motion tracking?

Tracking a moving object through space

- Up & down
- Side to side
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- How fast
- Where is it facing/pointing
- How is it turning
- Relative to what

- Yaw, pitch & roll
- Gravity/Linear acceleration
- Velocity
- Heading
- Rotational rate
- Absolute reference
What makes for “good” motion tracking?

- **Accurate**
  - How closely does it follow real movement?
  - Does it stay accurate over time?

- **Responsive**
  - How quickly does it react to movement?
  - Lack of lag – low latency

- **Noise-free and smooth**
  - Not jerky or sudden

- **Robust**
  - Unaffected by outside disturbances
  - Noise, magnetic anomalies, temp changes
How do we track motion?

9-axis sensing

- Gyroscope
- Accelerometer
- Magnetic sensors
## Sensor Measurements

<table>
<thead>
<tr>
<th></th>
<th>Gyroscope</th>
<th>Accelerometer</th>
<th>Magnetic sensors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yaw</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Pitch &amp; Roll</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Gravity</td>
<td></td>
<td>x</td>
<td></td>
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<tr>
<td>Velocity</td>
<td></td>
<td>x</td>
<td></td>
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<tr>
<td>Heading</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Rotational Rate</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Absolute reference</td>
<td></td>
<td>x</td>
<td>x</td>
</tr>
</tbody>
</table>
# Sensor data pitfalls

<table>
<thead>
<tr>
<th>Bias drift/error</th>
<th>Gyroscope</th>
<th>Accelerometer</th>
<th>Magnetic sensors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Noise</td>
<td></td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Magnetic disturbance</td>
<td></td>
<td></td>
<td>x</td>
</tr>
</tbody>
</table>
Gyro Bias

![Graph showing Gyro Bias over time]

- **Bias Change (degrees/sec)**
- **Time (minutes)**

- Ideal
- Uncorrected
Accelerometer noise

![Graph showing accelerometer noise with time (s) on the x-axis and accelerometer output (mg) on the y-axis. The graph compares ideal, industrial, and consumer accelerometers.](image)

- Ideal
- Industrial Accel
- Consumer Accel

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Magnetic interference
How to improve motion sensing?

- Better signal capture from sensors
- Better fusion to compensate for sensor inadequacies
Magnetic Sensor

Hall-Effect

Magneto-Inductive
Magnetic Sensor

Hall-Effect "compass" sensor most widely deployed

- Small Size
- Low power
- Low cost
Magnetic Sensor

Hall-Effect “compass” sensor

- Small Size
- Low power
- Low cost
- *Noisy*
- *Low resolution*

<table>
<thead>
<tr>
<th></th>
<th>Hall-Effect Sensor</th>
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<tbody>
<tr>
<td>Range</td>
<td>±1200 µT</td>
</tr>
<tr>
<td>Resolution</td>
<td>300 nT/LSB</td>
</tr>
<tr>
<td>Noise</td>
<td>500 nT</td>
</tr>
<tr>
<td>Current @ 8 Hz</td>
<td>0.3 mA</td>
</tr>
<tr>
<td>Operating Temp.</td>
<td>-40 to +85 °C</td>
</tr>
</tbody>
</table>
Magnetic Sensor

Magneto-inductive magnetic sensor

- Low power
- Low cost
- 15x better resolution
- 28x less noise
Comparison

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<th>Hall-Effect Sensor</th>
<th>Magneto-Inductive Sensor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range</td>
<td>±1200 µT</td>
<td>±800 µT*</td>
</tr>
<tr>
<td>Resolution</td>
<td>300 nT/LSB</td>
<td>20 nT/LSB</td>
</tr>
<tr>
<td>Noise</td>
<td>500 nT</td>
<td>30 nT</td>
</tr>
<tr>
<td>Current @ 8 Hz</td>
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<td>0.2 mA</td>
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</table>

*Increased range can be traded off against reduced resolution for the magneto-inductive sensor, but ±800 µT of range is sufficient for most applications.
Mag Comparison

- Magnetic Field (µT) vs. Heading (degrees)

Legend:
- Ideal
- Hall Effect
- Mag Inductive
Mag Comparison

Bias Change (degrees/sec) vs. Time (minutes)

- Ideal
- Uncorrected
- Corrected-Hall Effect
- Corrected-Mag Inductive
...for more accurate heading
Slow Rotation Test
Slow Rotation Test

![Graph showing heading (degrees) vs. time (seconds) for Ideal, Hall Effect, and Magneto-Inductive]

- **Ideal**
- **Hall Effect**
- **Magneto-Inductive**
Heading Error during Rotation

![Graph showing heading error during rotation with time on the x-axis and heading error on the y-axis. The graph compares ideal, Hall Effect, and Magneto-Inductive systems.]
Adding a Magnetic Distortion
Slow Rotation Test – *More Weighting for Hall Effect Mag*

![Graph showing heading vs time for ideal, Hall Effect, and Magneto-Inductive sensors.](image)
Magnetic Sensors

The performance of the magnetic sensor *does* make a difference

- 15x better resolution
- 28x less noise
9-axis motion tracking
with higher performance magnetic sensors.

- **Accurate**
  - How closely does it follow real movement?
  - Does it stay accurate

- **Responsive**
  - How quickly does it react to movement?
  - Lack of lag

- **Noise-free and smooth**
  - Not jerky or sudden

- **Robust**
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Summary

Accurately tracking a moving object through space is possible...

- Up & down
- Side to side
- Back & forth
- How fast
- Where is it facing/pointing
- How is it turning
- Relative to what

- Yaw, pitch & roll
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Thank you

Any questions?