Technical Note
I²C Communications with Honeywell Digital Output Force Sensors

1.0 INTRODUCTION
The I²C bus is a simple, serial 8-bit oriented computer bus for efficient I²C (Inter-IC) control. It provides good support for communication between different ICs across short circuit-board distances, such as interfacing microcontrollers with various low speed peripheral devices. For detailed specifications of the I²C protocol, see Version 2.1 (January 2000) of the I²C Bus Specification (source: NXP Semiconductor at http://www.nxp.com/acrobat_download/literature/9398/39340011.pdf).

Each device connected to the bus is software addressable by a unique address and a simple master/slave relationship that exists at all times. The output stages of devices connected to the bus are designed around an open collector architecture.

Because of this, pull-up resistors to +VDD must be provided on the bus. Both SDA and SCL (Serial Clock Line) are bidirectional lines, and it is important to system performance to match the capacitive loads on both lines. In addition, in accordance with the I²C specification, the maximum allowable capacitance on either line is 400 pF to ensure reliable edge transitions at 400 kHz clock speeds (see Figure 1).

When the bus is free, both lines are pulled up to +VDD. Data on the I²C-bus can be transferred at a rate up to 100 kbit/s in the standard mode, or up to 400 kbit/s in the fast mode.

Figure 1. I²C Bus Configuration

2.0 DATA TRANSFER WITH I²C OUTPUT FORCE SENSORS
Honeywell's digital output force sensors are designed to work as slaves and will therefore only respond to requests from a master device. Following the address and read bit from the master, Honeywell digital output force sensors are designed to output up to four bytes of data, depending on the sensor options and application needs. In all cases, the first two data bytes are the compensated force output, along with sensor status bits. The third and fourth bytes are for optional compensated temperature output.

2.1 Sensor Address
Each sensor is referenced on the bus by a 7-bit slave address. The default address for Honeywell force sensors is 40 (28 hex). Other available standard addresses are: 56 (38 hex), 72 (48 hex), 88 (58 hex), 104 (68 hex), 120 (78 hex), 136 (88 hex) and 152 (98 hex). (Other custom values are available. Please contact Honeywell Customer Service.)

2.2 Force Reading (see Figure 2)
To read out a compensated force reading, the master generates a Start condition and sends the sensor slave address followed by a Read bit. After the sensor generates an Acknowledge (ACK), it will transmit up to four bytes of data: the first two bytes containing the compensated force output, and the second two bytes containing the optional compensated temperature output. The master must acknowledge the receipt of each byte, and can terminate the communication by sending a Not Acknowledge (NACK) bit followed by a stop bit after receiving both bytes of data.

2.3 Temperature Reading
The optional corrected temperature data can be read out with either 8-bit or 11-bit resolution. By reading out the third byte of data from the sensor, the 8-bit compensated temperature value can be read. Further, by reading out the fourth byte of data, the complete 11-bit optional compensated temperature value can be read. The 8-bit value gives an approximate 0.8 °C resolution, while the 11-bit value gives an approximate 0.1 °C resolution. When reading the full 11-bit resolution temperature output, the five least significant bits of the fourth data byte are “Do Not Care” and should be ignored.
Technical Note
I2C Communication with Honeywell Digital Output Force Sensors

Figure 2. I2C Force and Temperature Measurement Packets Readout

Table 1. Diagnostic Conditions Indicated by Status Bits

<table>
<thead>
<tr>
<th>Status Bits</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1  S0</td>
<td></td>
</tr>
<tr>
<td>0  0</td>
<td>normal operation, valid data</td>
</tr>
</tbody>
</table>
| 0  1        | device in command mode

2.4 Status Bits

Honeywell digital output force sensors offer both standard and optional diagnostics to ensure robust system operation in critical applications. The diagnostic states are indicated by the first two Most Significant Bits of Data Byte 1. Four diagnostic states are indicated by the two status bits (see Table 1).

Optional diagnostics for Honeywell digital output force sensors consist of:
- Loss of sense element connection
- Short circuit of sense element

When the two status bits are “11”, one of the these two diagnostic faults is indicated.

When the status bits read “10”, “stale” data is indicated. This means that the data that already exists in the sensor’s output buffer has already been fetched by the master, and has not yet been updated with the next data from the current measurement cycle. This can happen when the master polls the data quicker than the sensor can update the output buffer.

(Please contact Honeywell Customer Service with questions regarding the availability of optional force sensor diagnostics.)

Standard diagnostics for Honeywell digital output force sensors consist of an EEPROM (Electrically Erasable Programmable Read-Only Memory) signature used to validate the EEPROM contents during startup. In the event that any EEPROM content changes after calibration, a diagnostic condition will be flagged.
3.0 CALCULATION OF FORCE FROM THE DIGITAL OUTPUT

For Honeywell digital output force sensors, the output of the device can be expressed by the transfer function of the device as shown in Equation 1.

**Equation 1: Force Sensor Transfer Function**

\[
Output = \frac{(Output_{\text{max}} - Output_{\text{min}})}{\text{Rated Force Range}} \times (\text{Force}_{\text{applied}}) + Output_{\text{min}}.
\]

Rearranging this equation to solve for force, we get Equation 2:

**Equation 2: Force Output Function**

\[
\text{Force} = \frac{(Output - Output_{\text{min}})}{(Output_{\text{max}} - Output_{\text{min}})} \times \text{Rated Force Range}
\]

Where:
- \(Output_{\text{max}}\) = output at maximum force [counts]
- \(Output_{\text{min}}\) = output at minimum force [counts]
- \(\text{Rated Force Range}\) = maximum value of force range (N, lb, g, or kg)
- \(\text{Force}_{\text{applied}}\) = minimum value of force range (N, lb, g, or kg)
- \(\text{Force}\) = force reading (N, lb, g, or kg)
- \(Output\) = digital force reading [counts]

Example: The force is calculated for a 10 N force sensor with a 10% to 90% calibration and a force output of 6880 (decimal) counts:

\[
\begin{align*}
Output_{\text{max}} &= 14745 \text{ counts (90\% of 2^14 counts or 0x3999)} \\
Output_{\text{min}} &= 1638 \text{ counts (10\% of 2^14 counts or 0x0666)} \\
\text{Rated Force Range} &= 10 \text{ N} \\
\text{Force}_{\text{applied}} &= 10 \text{ N} \\
\text{Force} &= \text{force in N} \\
Output &= 6880 \text{ counts}
\end{align*}
\]

\[
\begin{align*}
\text{Force} &= \frac{(6880 - 1638) \times 10}{(14745 - 1638)} \\
\text{Force} &= \frac{5242 \times 10}{13107} \\
\text{Force} &= 4 \text{ N}
\end{align*}
\]

4.0 CALCULATION OF OPTIONAL TEMPERATURE FROM THE DIGITAL OUTPUT

For Honeywell digital output force sensors with the optional compensated temperature output, the output can be converted to °C using Equation 3:

**Equation 3: Temperature Conversion Function**

\[
\text{Temperature (°C)} = \frac{\text{Output (dec)} \times 200}{2047} - 50
\]

If the 8-bit temperature output is used, the data must first be shifted left by three bits and have the three Least Significant Bits set to zeros for the equation to work.

Example: The optional compensated temperature output is calculated for a sensor with an 8-bit temperature output of 255:

**Step 1:** Left shift the above 8-bit value by three places and append the three LSBs with zeros:

Digital Temperature Output (8-bit) = 255 = 1111111b
1111111000b = 2040

**Step 2:** Use the adjusted value and plug into Equation 3:

\[
\text{Temperature (°C)} = \frac{2040 \times 200}{2047} - 50
\]

Temperature = 149.31 °C

Example: The optional compensated temperature is calculated for a sensor with an 11-bit temperature output of 1456:

**Step 1:** Plug the digital temperature output value into Equation 3:

\[
\text{Temperature (°C)} = \frac{1456 \times 200}{2047} - 50
\]

Temperature = 92.26 °C
Technical Note
I²C Communication with Honeywell Digital Output Force Sensors

5.0 TIMING AND LEVEL PARAMETERS (see Figure 3)

Figure 3. I²C Bus Timing Diagram and Parameters

<table>
<thead>
<tr>
<th>I²C Parameter</th>
<th>Symbol</th>
<th>Minimum</th>
<th>Typical</th>
<th>Maximum</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCL clock frequency</td>
<td>f_SCL</td>
<td>100</td>
<td>—</td>
<td>400</td>
<td>kHz</td>
</tr>
<tr>
<td>Start condition hold time relative to SCL edge</td>
<td>t_HDSTA</td>
<td>0.1</td>
<td>—</td>
<td>—</td>
<td>μs</td>
</tr>
<tr>
<td>Minimum SCL clock width¹:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>low</td>
<td>t_LOW</td>
<td>0.6</td>
<td>—</td>
<td>—</td>
<td>μs</td>
</tr>
<tr>
<td>high</td>
<td>t_HIGH</td>
<td>0.6</td>
<td>—</td>
<td>—</td>
<td>μs</td>
</tr>
<tr>
<td>Start condition setup time relative to SCL edge</td>
<td>t_SUPSTA</td>
<td>0.1</td>
<td>—</td>
<td>—</td>
<td>μs</td>
</tr>
<tr>
<td>Data hold time on SDA relative to SCL edge</td>
<td>t_HDDAT</td>
<td>0</td>
<td>—</td>
<td>—</td>
<td>μs</td>
</tr>
<tr>
<td>Data set-up time on SDA relative to SCL edge</td>
<td>t_SUDPAT</td>
<td>0.1</td>
<td>—</td>
<td>—</td>
<td>μs</td>
</tr>
<tr>
<td>Stop condition setup time on SCL</td>
<td>t_SUSTO</td>
<td>0.1</td>
<td>—</td>
<td>—</td>
<td>μs</td>
</tr>
<tr>
<td>Bus free time between stop condition and start condition</td>
<td>t_BUS</td>
<td>2</td>
<td>—</td>
<td>—</td>
<td>μs</td>
</tr>
<tr>
<td>Output level:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>low</td>
<td>Out_LOW</td>
<td>—</td>
<td>0</td>
<td>0.2</td>
<td>V_DD</td>
</tr>
<tr>
<td>high</td>
<td>Out_HIGH</td>
<td>0.8</td>
<td>1</td>
<td>—</td>
<td>V_DD</td>
</tr>
<tr>
<td>Pull-up resistance on SDA and SCL</td>
<td>R_P</td>
<td>1</td>
<td>—</td>
<td>50</td>
<td>kOhm</td>
</tr>
</tbody>
</table>

¹Combined low and high widths must equal or exceed minimum SCL period.

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