Interface and Data Format Specification for sensors

(v3 sensor boards)

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Waggle Sensor Array

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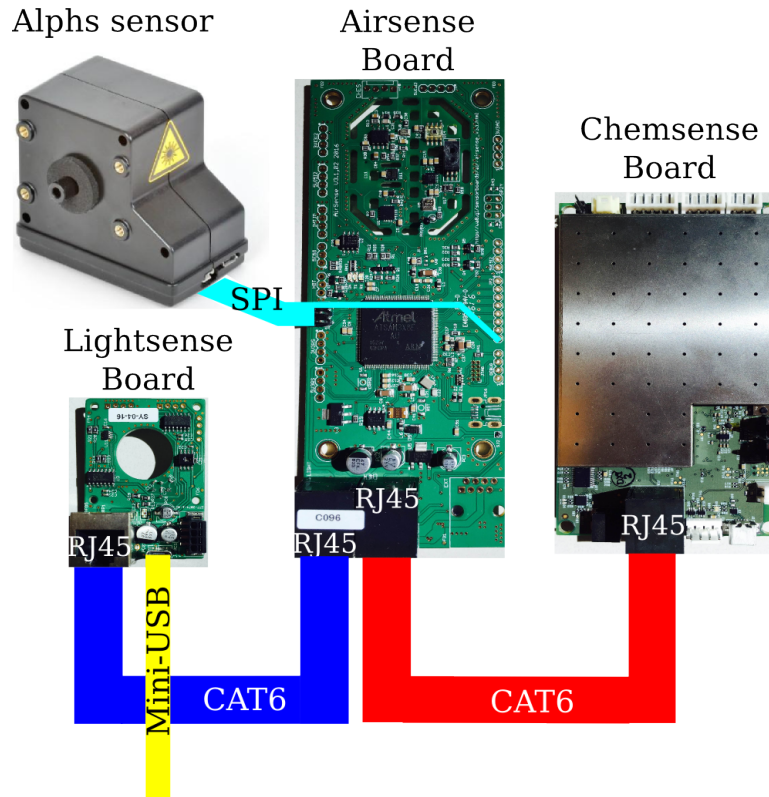
Figure 1: Connections between the sensor boards and the sensor

Physical connections between sensor boards and sensors are shown in the Figure 1. Airsense board is connected to lightsense board and chemsense board through CAT6 cable. Airsense and lightsense deliver data through I2C communication, and chemsense board delivers data through serial3 communication. All sensor data from airsense, lightsense, and chemsense board are delivered to nodecontroller thourgh USB connect attached on lightsense board. Alpha sensor will be conncted to Airsense board using SPI communication line. Then all the sensor data will be delivered through the USB connect on lighsense board.

2 Data Transmission

The data from the sensor boards is sent as a formatted unit of data — a transmission packet. A transmission packet is composed of several data sub-packets, each of which carries information pertaining to the parameter listed in the sub-packet. The transmission packet format and the data sub-packets are described here.

2.1 Transmission Packet

A transmission packet can be broken down into 6 segments. The structure of the transmission packet (and the data sub-packet) relies on byte positions and predefined values for some segments. The first segment is the start byte or the preamble. The preamble is followed by the packet sequence number and protocol version, each of which are 4 bits long and are together packed into a single byte. Next, a one byte field that reports the length of the data which follows it immediately. The data segment is followed by a single CRC byte, and finally the packet ends with a one byte postscript. The table below lists the packet and the static values, if any, for each of the segments.

Field	Value	Segment	Length
Preamble	0xAA	1	1 Byte
Packet Sequence Number	Variable	2	1 Nibble
Protocol version	0x00	2	1 Nibble
Length of data (not whole packet)	Variable	3	1 Byte
Data	Variable	4	Variable
CRC of data (not whole packet)	Variable	5	1 Byte
Postscript	0x55	6	1 Byte

Table 1: Transmission Packet Segments

The table below illustrates how the segments are organized in a transmission packet.

Preamble	Seq. Number | Prot. Ver.	Data Length	Data	CRC	Postscript
1st Byte	2nd Byte	3rd Byte	up to 255 Bytes	Penultimate Byte	Final Byte

Table 2: Transmission Packet structure

2.2   Data Packer CRC

To validate the data transmitted from the sensor board, a CRC value for the data is calculated and transmitted as part of the data packet. The Maxim 1-Wire CRC polynomial is used for calculating the CRC. On receiving the data packet, the CRC of the data packet is recalculated and compared with the value transmitted as part of the packet. If the two CRC values match, the transmission is error-free. The equivalent polynomial function of the CRC is:

$$CRC = x^8 + x^5 + x^4 + 1.$$

Further description of the Maxim 1-Wire CRC is available in Maxim Application Note 27. Below are the Python and C implementations of the CRC calculator. The CRC implementations below take a data byte and the previous CRC as inputs, and return the new CRC as return value.

Python Code:

```python
def calc_crc (data_byte ,CRC_Value )
    CRC_Value = ord(data_byte) ^ CRC_Value
    for j in range(8):
    if (CRC_Value  & 0x01):
        CRC_Value  = (CRC_Value  >> 0x01) ^ 0x8C
    else:
        CRC_Value  =  CRC_Value  >> 0x01
return  CRC_Value
```

C Code:

```c
unsigned char  CRC_CALC (unsigned char data , unsigned char crc)
{
        unsigned char i;
        crc ^= data;
        for (i=0x00; i < 0x08; i++)
```

```
        {
                if ( crc & 0 x01 )
                        crc = ( crc >> 0 x01 ) ^ 0 x8C ;
                else
                        crc =  crc >> 0 x01 ;
        }

        return ( crc );
}
```

2.3   Data Sub-packets

The data segment of the transmission packet is further broken down into many sub-packets. The sub-packet starts with a source identifier. One bit validity field and seven bits "length of the sub-packet" field are packed together as the next byte. The length field counts the number of bytes following it which make up the sub-packet. The table below shows the organization of a sub-packet. The validity bit is set to 0 if the sensor represented in the sub-packet is dead, disabled, unconnected, unresponsive or if data could not be collected from the sensor in the time window. Instead of recreating the full packet in the buffer, the particular sub-packet which is the sensor segment is marked as invalid is not packed into a whole packet. If the field is set to 1, it indicates a valid measurement/reading. The seven bits length field restricts the size of the sub-packet to 127 bytes.

Source ID	1-bit Validity [0: invalid, 1: valid]‖ 7-bits Data Length	Data
One Byte	One Byte	up to 127 Bytes

3   Data Formats

The data sent in each sub-packet is encoded in one or more formats. Currently we define eight formats for various types of data including integers, bytes, and floating point numbers. The numerical range of these representations is restricted to within the bounds of values that we expect from the various sensors and other sources. Thus the encoding schemes are specifically designed to effectively and efficiently encode the values expected in the sensor streams. The eight formats, and the encoding schemes are listed below.

Format	Number of Bytes Used	Value Represented	Value Range
1	2	unsigned int_16 input	$0 - 65535$
2	2	int_16 input	$\pm\{0 - 32767\}$
3	6	byte input[6]	$0x00 - 0xffffffffffff$
4	3	unsigned long_24 input	$0 - 16777215$
5	3	long_24 input	$\pm\{0 - 8388607\}$
6	2	float input	$\pm\{0 - 127.99\}$
7	4	byte input[4]	$0x00 - 0xffffffff$
8	2	float input	$\pm\{0 - 31.999\}$

Table 3: Data formats

3.1   Format 1

This 2 byte format is used to transmit an integer between 0 and 65535. The number is split and serialized as follows –

8 Most Significant Bits	8 Least Significant Bits
Byte[0]	Byte[1]

3.2   Format 2

This 2 byte format is used to transmit an integer between -32767 and 32767. The number is split and serialized as follows –

Sign Bit | 7 Most Significant Bits	8 Least Significant Bits
Byte[0]	Byte[1]

The Sign Bit which is the most significant bit in Byte 0 is set as follows —

Positive Integer	0
Negative Integer	1

3.3   Format 3

This 6 byte format is used to transmit an array of 6 bytes. The array is serialized as follows –

Array[0]	Array[1]	Array[2]	Array[3]	Array[4]	Array[5]
1st Byte	2nd Byte	3rd Byte	4th Byte	5th Byte	6th Byte

3.4   Format 4

This 3 byte format is used to transmit an integer between 0 and 16777215. The number is split and serialized as follows −

8 Most Significant Bits	Bits $15 - 8$	8 Least Significant Bits
Byte 0	Byte 1	Byte 2

3.5   Format 5

This 3 byte format is used to transmit an integer between -8388607 and 8388607. The number is split and serialized as follows −

Sign Bit | 7 Most Significant Bits	Bits $15 - 8$	8 Least Significant Bits
Byte 0	Byte 1	Byte 2

The Sign Bit which is the most significant bit in Byte 0 is set as follows —

Positive Integer	0
Negative Integer	1

3.6   Format 6

This 2 byte format is used to transmit a floating point number between -127.99 and 127.99. Only 2 fractional places are allowed in this format and the number is serialized as follows −

Sign Bit| 7 bit representation of Integer part	0 | 7 bit representation of the Fractional part
Byte 0	Byte 1

As shown above, the leading bit of the Byte 1 is always set to 0, and the Sign Bit which is the most significant bit of Byte 0 is set as follows —

Positive Number	0
Negative Number	1

3.7   Format 7

This 4 byte format is used to transmit an array of 4 bytes. The array is serialized as follows –

Array[0]	Array[1]	Array[2]	Array[3]
Byte 0	Byte 1	Byte 2	Byte 3

3.8   Format 8

This 2 byte format is used to transmit a floating point number between -31.999 and 31.99. Only 3 fractional places are allowed in this format and the number is serialized as follows –

Sign Bit| 5 bit representation of Integer	2 most significant bits of fraction	8 least significant bits of the fraction
Byte 0	Byte 1

As shown above, the format uses 5 bits for representing the integer part and 10 bits to represent the fractional part. The Sign Bit which is the most significant bit of Byte 0 is set as follows —

Positive Number	0
Negative Number	1

4   Sub-packets

As shortly explained in document section 2.3, data sub-packets are generated depending on its designated data format and length. The first byte of the sub-packet is sensor ID for each parameter, and the second byte means validity of the packet and length of the sensor data. The packet validity is initially 0, and it will be changed to 1 when each sub-packet gets sensor value from sensor. And after a transmission packet is trasmitted, the validity becomes 0 again. The form of sub-packet is shown below.

Source ID	1-bit Validity	7-bits Sensor Data Length	Data
One Byte	One Byte	up to 127 Bytes

4.1   Parameters

The sensor boards output a set of parameters which are identified by a unique ID. Each parameter has a set of values associated with it which are encoded in an appropriate data format. The table below lists the various parameters produced by the sensor boards, the unique source ID used to identify them, the values produced by them and the format in which the value is encoded.

Table 4: Data sub-packet structure (each row is a "chunk")

Parameter	Source ID	Values and Formats
Airsense board		
Airsense/Lightsense MAC address	0x00	MAC Address – Format 3
TMP112	0x01	Temperature – Format 6
HTU21D	0x02	Temperature and Humidity – Format 6
HIH4030	0x03	Humidity – Format 1
BMP180	0x04	Temperature – Format 6 & Pressure – Format 4
PR103J2	0x05	Temperature – Format 1
TSL250RD	0x06	Visible Light – Format 1
MMA8452Q	0x07	Three Accelerations and Vibration – Format 6
SPV1840LR5H-B	0x08	RMS Sound Level – Format 1
TSYS01	0x09	Temperature – Format 6
Lightsense board		
HMC5883L	0x0A	Three Magnetic Fields – Format 8
HIH6130	0x0B	Temperature and Humidity – Format 6
APDS-9006-020	0x0C	Visible Light – Format 1
TSL260RD	0x0D	IR Light – Format 1
TSL250RD	0x0E	Visible Light – Format 1
MLX75305	0x0F	Light – Format 1
ML8511	0x10	Light – Format 1
MLX90614	0x12	Temperature – Format 6
		Continued on next page

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Parameter	Source ID	Values and Formats
TMP421	0x13	Temperature – Format 6
Chemsense board		
Total reducing gases	0x15	Raw Concentration – Format 5
Nitrogen dioxide	0x17	Raw Concentration – Format 5
Ozone	0x18	Raw Concentration – Format 5
Hydrogen sulphide	0x19	Raw Concentration – Format 5
Total oxidizing gases	0x1A	Raw Concentration – Format 5
Carbon monoxide	0x1B	Raw Concentration – Format 5
Sulfur dioxide	0x1C	Raw Concentration – Format 5
SHT25	0x1D	Temperature & Humidity – Format 2
LPS25H	0x1E	Temperature – Format 2 & Pressure – Format 4
Si1145	0x1F	UV intensity – Format 1
Chemsense MAC address	0x20	MAC Address – Format 3
CO ADC temp	0x21	ADC temperature – Format 2
IAQ IRR ADC temp	0x22	ADC temperature – Format 2
O3 NO2 ADC temp	0x23	ADC temperature – Format 2
SO2 H2S ADC temp	0x24	ADC temperature – Format 2
CO LMP temp	0x25	ADC temperature – Format 2
Accelerometer	0x26	Three Accelerations – Format 2 & Vibration – Format 4
Gyro	0x27	Three Orientations – Format 2 & Orientation Index – Format 4
Alpha sensor		
Histogram	0x28	Various particle information including Particulate Matter
Firmware	0x29	Firmware version – unsigned integer
Configuration A	0x30	Sensor Configuration packet A – unsigned integer
Configuration B	0x31	Sensor Configuration packet B – unsigned integer
Configuration C	0x32	Sensor Configuration packet C – unsigned integer
Configuration D	0x33	Sensor Configuration packet D – unsigned integer

Each parameter and its values are composed into a sub-packet based on the format described in document section 2.3. In the case of parameters with 2 or more values, the encoded values are arranged in the sub-packets sequentially. The context of each parameter, its utility and the arrangement of its values is described below. In all the tables below, the validity bit is set to 1. The parameter descriptions below are aggregated based on the sensor-board they are situated on - Airsense, Lightsense and Chemsense.

4.2   Airsense:

4.2.1   Airsense/Lightsense MAC address

This is a six byte ID that uniquely identifies each Airsense board. This MAC address is also applied to each Lightsense board which has the same board number. The ID is provided by a DS2401 1-Wire DSN chip. The 1-byte family ID and CRC provided by the DSN chip are omitted, and the rest six bytes are used as the Unique ID. The Unique ID uses Format 3 for encoding and the arrangement is listed below.

0x00	0x86	ID in Format 3
Byte[0]	Byte[1]	Bytes[2 − 7]

4.2.2   TMP112

TMP112 is a digital temperature sensor, which provides the temperature values in centigrade.

0x01	0x82	Temperature in Format 6
Byte[0]	Byte[1]	Bytes[2 − 3]

Value	Board Output	Post-Processing Mode	Post-processed Output
Temperature	°C	None	None

4.2.3   HTU21D

HTU21D is a digital temperature and humidity sensor, which provides relative humidity value (%RH) and temperature value in centigrade.

0x02	0x84	Temperature in Format 6	%RH in Format 6
Byte[0]	Byte[1]	Bytes[2 − 3]	Bytes [4 − 5]

Value	Board Output	Post-Processing Mode	Post-processed Output
Temperature	°C	None	None
Relative Humidity	%RH	Linear Fitting	%RH

4.2.4   HIH4030

HIH4030 is an analog humidity sensor, which provides an analog voltage representative of the relative humidity. The analog voltage is converted and packed into Format 1 using a 10-bit ADC.

0x03	0x82	RH in Format 1
Byte[0]	Byte[1]	Bytes[2 − 3]

Value	Board Output	Post-Processing Mode	Post-processed Output
Relative Humidity	raw integer	Bulk Curve Fitting	%RH

4.2.5 BMP180

BMP180 is an digital temperature and barometric pressure sensor, which provides temperature in centigrade and pressure in hectopascals.

0x04	0x85	Temperature in Format 6	Pressure in Format 4
Byte[0]	Byte[1]	Bytes[2 − 3]	Bytes [4 − 6]

Value	Board Output	Post-Processing Mode	Post-processed Output
Temperature	°C	None	None
Atmospheric Pressure	Pa	None	None

4.2.6 PR103J2

PR103J2 is an analog temperature sensor whose resistance changes with change in temperature. The sensor is implemented in a voltage divider circuit, and the center-tap voltage is converted and packed into Format 1 using a 10-bit ADC.

0x05	0x82	Temperature in Format 1
Byte[0]	Byte[1]	Bytes[2 − 3]

Value	Board Output	Post-Processing Mode	Post-processed Output
Temperature	raw integer	Bulk Curve Fitting	°C

4.2.7 TSL250RD

TSL250RD is an analog visible light sensor that produces an analog voltage that is representative of the irradiance measured in $\mu W/cm^2$. The output voltage of the sensor is converted and packed into Format 1 using a 10-bit ADC.

0x06	0x82	Light intensity in Format 1
Byte[0]	Byte[1]	Bytes[2 − 3]

Value	Board Output	Post-Processing Mode	Post-processed Output
Light Intensity	raw integer	Bulk Curve Fitting	$\mu W/cm^2$

4.2.8   MMA8452Q

MMA8452Q is a digital three-axis accelerometer. The accelerations in three orthogonal directions, x, y and z, as a multiple of acceleration due to gravity (g) are obtained from the sensor, and a vibration value (represented as multiple of g) is calculated using high-frequency time series data from the three axis.

0x07	0x88	Acc. X in Format 6	Acc. Y in Format 6	Acc. Z in Format 6	Vibration in Format 6
Byte[0]	Byte[1]	Bytes[2 − 3]	Bytes[4 − 5]	Bytes[6 − 7]	Bytes[8 − 9]

Value	Board Output	Post-Processing Mode	Post-processed Output
Acc. X	g	none	none
Acc. Y	g	none	none
Acc. Z	g	none	none
Vibration	g	none	none

4.2.9   SPV1840LR5H-B

SPV1840LR5H is a MEMS microphone that is sampled at high frequency to obtain the peaks and calculate the sound intensity for a time window. The raw calculated intensity is represented as a 16-bit integer value using Format 1.

0x08	0x82	Sound Intensity in Format 1
Byte[0]	Byte[1]	Bytes[2 − 3]

Value	Board Output	Post-Processing Mode	Post-processed Output
Sound Intensity	raw integer	Bulk Curve Fitting	dB

4.2.10   TSYS01

TSYS01 is a digital temperature sensor, which provides the temperature values in centigrade.

0x09	0x82	Temperature in Format 6
Byte[0]	Byte[1]	Bytes[2 − 3]

Value	Board Output	Post-Processing Mode	Post-processed Output
Temperature	°C	None	None

4.3   Lightsense:

4.3.1   HMC5883L

HMC5883L is a digital three-axis magnetometer. The magnetic field strengths in three orthogonal directions, x, y and z are obtained from the sensor.

0x0A	0x88	Field strength X in Format 8	Field strength Y in Format 8	Field strength Z in Format 8
Byte[0]	Byte[1]	Bytes[2 − 3]	Bytes[4 − 5]	Bytes[6 − 7]

Value	Board Output	Post-Processing Mode	Post-processed Output
Mag. Field X	Gauss	none	none
Mag. Field Y	Gauss	none	none
Mag. Field Z	Gauss	none	none

4.3.2   HIH6130

HIH6130 is a digital temperature and humidity sensor, which provides relative humidity value (%RH) and temperature value in centigrade.

0x0B	0x84	Temperature in Format 6	%RH in Format 6
Byte[0]	Byte[1]	Bytes[2 − 3]	Bytes[4 − 5]

Value	Board Output	Post-Processing Mode	Post-processed Output
Temperature	°C	None	None
Relative Humidity	%RH	None	None

4.3.3   APDS-9006-020

APDS-9006-020 is an analog visible light sensor that produces an analog voltage that is representative of the general luminance. The output voltage of the sensor is converted and packed into Format 1 using a 16-bit ADC.

0x0C	0x82	Raw luminance in Format 1
Byte[0]	Byte[1]	Bytes[2 − 3]

Value	Board Output	Post-Processing Mode	Post-processed Output
Ambient Light Intensity	raw integer	Bulk Curve Fitting	lux

4.3.4   TSL260RD

TSL260RD is an analog Near-infrared light sensor that produces an analog voltage that is representative of the irradiance measured in $\mu W/cm^2$. The output voltage of the sensor is converted and packed into Format 1 using a 16-bit ADC.

0x0D	0x82	Near-infrared intensity in Format 1
Byte[0]	Byte[1]	Bytes[2 − 3]

Value	Board Output	Post-Processing Mode	Post-processed Output
Nera-infrared Intensity	raw integer	Bulk Curve Fitting	$\mu W/cm^2$

4.3.5   TSL250RD

TSL250RD is an analog visible light sensor that produces an analog voltage that is representative of the irradiance measured in $\mu W/cm^2$. The output voltage of the sensor is converted and packed into Format 1 using a 16-bit ADC.

0x0E	0x82	Light intensity in Format 1
Byte[0]	Byte[1]	Bytes[2 − 3]

Value	Board Output	Post-Processing Mode	Post-processed Output
Ambient Light Intensity	raw integer	Bulk Curve Fitting	$\mu W/cm^2$

4.3.6   MLX75305

MLX75305 is an visible light sensor that produces an analog output that is representative of the light intensity. The output voltage of the sensor is converted and packed into Format 1 using a 16-bit ADC.

0x0F	0x82	Light intensity in Format 1
Byte[0]	Byte[1]	Bytes[2 − 3]

Value	Board Output	Post-Processing Mode	Post-processed Output
Ambient Light Intensity	raw integer	Bulk Curve Fitting	$\mu W/cm^2$

4.3.7   ML8511

ML8511 is an ultra-violet light sensor that produces an analog output that is representative of the ultra-violet light intensity. The output voltage of the sensor is converted and packed into Format 1 using a 16-bit ADC.

0x10	0x82	UV intensity in Format 1
Byte[0]	Byte[1]	Bytes[2 − 3]

Value	Board Output	Post-Processing Mode	Post-processed Output
UV Light Intensity	raw integer	Bulk Curve Fitting	$\mu W/cm^2$

4.3.8   TMP421

TMP421 is a digital temperature sensor, which provides the temperature values in centigrade.

0x13	0x82	Temperature in Format 6
Byte[0]	Byte[1]	Bytes[2 − 3]

Value	Board Output	Post-Processing Mode	Post-processed Output
Temperature	°C	None	None

4.4   Chemsense:

4.4.1   Total reducing gases

This parameter provides the current output of the electrochemical ToR sensor. The cell current is quantified using an AFE that uses a 24-bit ADC to convert it into a signed digital value. This value is represented in Format 5.

0x15	0x83	Raw current value in Format 5
Byte[0]	Byte[1]	Bytes[2 − 3]

Value	Board Output	Post-Processing Mode	Post-processed Output
Concentration	raw integer	per-sensor	PPM

4.4.2   Nitrogen dioxide

This parameter provides the current output of the electrochemical NO_2 sensor. The cell current is quantified using an AFE that uses a 24-bit ADC to convert it into a signed digital value. This value is represented in Format 5.

0x17	0x83	Raw current value in Format 5
Byte[0]	Byte[1]	Bytes[2 − 3]

Value	Board Output	Post-Processing Mode	Post-processed Output
Concentration	raw integer	per-sensor	PPM

4.4.3   Ozone

This parameter provides the current output of the electrochemical O_3 sensor. The cell current is quantified using an AFE that uses a 24-bit ADC to convert it into a signed digital value. This value is represented in Format 5.

0x18	0x83	Raw current value in Format 5
Byte[0]	Byte[1]	Bytes[2 − 3]

Value	Board Output	Post-Processing Mode	Post-processed Output
Concentration	raw integer	per-sensor	PPM

4.4.4   Hydrogen sulphide

This parameter provides the current output of the electrochemical H_2S sensor. The cell current is quantified using an AFE that uses a 24-bit ADC to convert it into a signed digital value. This value is represented in Format 5.

0x19	0x83	Raw current value in Format 5
Byte[0]	Byte[1]	Bytes[2 − 3]

Value	Board Output	Post-Processing Mode	Post-processed Output
Concentration	raw integer	per-sensor	PPM

4.4.5   Total oxidizing gases

This parameter provides the current output of the electrochemical ToX sensor. The cell current is quantified using an AFE that uses a 24-bit ADC to convert it into a signed digital value. This value is represented in Format 5.

0x1A	0x83	Raw current value in Format 5
Byte[0]	Byte[1]	Bytes[2 − 3]

Value	Board Output	Post-Processing Mode	Post-processed Output
Concentration	raw integer	per-sensor	PPM

4.4.6   Carbon monoxide

This parameter provides the current output of the electrochemical CO sensor. The cell current is quantified using an AFE that uses a 24-bit ADC to convert it into a signed digital value. This value is represented in Format 5.

0x1B	0x83	Raw current value in Format 5
Byte[0]	Byte[1]	Bytes[2 − 3]

Value	Board Output	Post-Processing Mode	Post-processed Output
Concentration	raw integer	per-sensor	PPM

4.4.7   Sulfur dioxide

This parameter provides the current output of the electrochemical SO_2 sensor. The cell current is quantified using an AFE that uses a 24-bit ADC to convert it into a signed digital value. This value is represented in Format 5.

0x1C	0x83	Raw current value in Format 5
Byte[0]	Byte[1]	Bytes[2 − 3]

Value	Board Output	Post-Processing Mode	Post-processed Output
Concentration	raw integer	per-sensor	PPM

4.4.8   SHT25

SHT25 is a temperature and humidity sensor. The temperature and humidity raw values are encoded in Format 2.

0x1D	0x84	Raw temperature value in Format 2	Raw humidity value in Format 2
Byte[0]	Byte[1]	Bytes[2 − 3]	Bytes[4 − 5]

Value	Board Output	Post-Processing Mode	Post-processed Output
Temperature	100ths of °C	Linear Fitting	°C
Humidity	100ths of %RH	Linear Fitting	%RH

4.4.9   LPS25H

LPS25H is a temperature and pressure sensor. The temperature and pressure raw values are encoded in Format 2 and Format 4 respectively.

0x1E	0x85	Raw temperature value in Format 2	Raw pressure value in Format 4
Byte[0]	Byte[1]	Bytes[2 − 3]	Bytes[4 − 6]

Value	Board Output	Post-Processing Mode	Post-processed Output
Temperature	100ths of °C	Linear Fitting	°C
Atmospheric Pressure	Pa	None	None

4.4.10   Si1145

Si1145 is a light sensor. The raw output values from the sensor are encoded in Format 1, but the values need to be ignored since chemsense board firmware is not completed (July 2016).

0x1F	0x86	Raw UV intensity in Format 1
Byte[0]	Byte[1]	Bytes[2 − 3]

Value	Board Output	Post-Processing Mode	Post-processed Output
UV Intensity	fixed hex integer	None	None
VL Intensity	fixed hex integer	None	None
IR Intensity	fixed hex integer	None	None

4.4.11   Chemsense MAC address

This is a six byte ID that uniquely identifies each Chemsense board. The Unique ID uses Format 3 for encoding and the arrangement is listed below.

0x20	0x86	ID in Format 3
Byte[0]	Byte[1]	Bytes[2 − 7]

4.4.12   ADC Temperatures

Chemsense board measures temperature of sensor ADCs. This includes five parameters which are:

- CO ADC Temp

- IAQ/IRR ADC Temp

- O3/NO2 ADC Temp

- SO2/H2S ADC Temp

- CO CMT Temp

All of them give ADC temperature in 100ths of degree celsious. Format 2 is used for encoding and the arrangement is listed below. No specific descriptions for each sensor data are given for now (July 2016).

Source ID (0x21 ∼ 0x25)	0x82	temperature in Format 2
Byte[0]	Byte[1]	Bytes [2 − 3]

Value	Board Output	Post-Processing Mode	Post-processed Output
Temperature	100ths of °C	Linear Fitting	°C

4.4.13 Accelerometer

The accelerations in three orthogonal directions, x, y and z, as a multiple of acceleration are obtained from the sensor, and a vibration index is calculated. Acceleration data are encoded in Format 2, and vibration index is encoded in Format 4. No specific descriptions for each sensor data are given for now (July 2016).

0x26	0x89	Acc. X in Format 2	Acc. Y in Format 2	Acc. Z in Format 2	Vibration in Format 4
Byte[0]	Byte[1]	Bytes[2 − 3]	Bytes[4 − 5]	Bytes[6 − 7]	Bytes[8 − 10]

Value	Board Output	Post-Processing Mode	Post-processed Output
Acc. X	raw integer	none	none
Acc. Y	raw integer	none	none
Acc. Z	raw integer	none	none
Vibration Index	raw integer	none	none

4.4.14 Gyro

The gyro in three orthogonal directions, x, y and z, as a multiple of acceleration are obtained from the sensor, and a orientation index is calculated. Gyro data are encoded in Format 2, and orientation index is encoded in Format 4. No specific descriptions for each sensor data are given for now (July 2016).

0x27	0x89	X in Format 2	Y in Format 2	Z in Format 2	Index in Format 4
Byte[0]	Byte[1]	Bytes[2 − 3]	Byte[4 − 5]	Bytes[6 − 7]	Bytes[8 − 10]

Value	Board Output	Post-Processing Mode	Post-processed Output
X Orientation	raw integer	none	none
Y Orientation	raw integer	none	none
Z Orientation	raw integer	none	none
Orientation Index	raw integer	none	none

4.5   Alpha Sensor:

In this document, concise Alpha sensor information is provided. For more information, refer to 'Firmware commands version 18.xls' and 'OPC-N2 Manual Issue December 2015.pdf' at 'waggle/docs/alphasense-opc-n2'.

4.5.1   Histogram

This parameter provides various information as listed below. **All data from the alpha sensor is LSB first**.

- Bin Counts. Bin Counts (Bin0 - Bin15) are unsinged 16 bit integer variables (Bytes[2 − 33]).

- An unsigned 8-bit integer represents the average amount of time that particles sized in the stated bin took cross the laser beam of the sensor. Value 10 represents 3.33 μs (Bytes[36 − 39]).

- The sample flow rate in ml/s is provided as a float variable (Bytes[40 − 43]).

- Temperature and Pressure alternating. Temperature is an unsigned 32-bit integer that represents temperature in Celsious multiplied by 10. Pressure is an unsigned 32-bit integer that represents pressure in pascals (Bytes[44 − 45]).

- Actual sampling period of a measure of the historgam in seconds provided as 4 bytes of float variables (Bytes[46 − 49]).

- The least significat 16-bit of the sum of the counts in all the histogram bins is provided by unsigned 16bit integers (Bytes[50 − 51]).

- A float variable occupying 4 bytes for PM1. Unit is μg/m^3 (Bytes[52 − 55]).

- A float variable occupying 4 bytes for PM2.5. Unit is μg/m^3 (Bytes[56 − 59]).

- A float variable occupying 4 bytes for PM10. Unit is μg/m^3 (Bytes[60 − 63]).

0x28	0xBE	Various sensor information as listed above
Byte[0]	Byte[1]	Bytes[2 − 63]

Value	Board Output	Post-Processing Mode	Post-processed Output
Bin Count	raw integer	None	None
Average Time	value 10 = 3.33 μs	None	None
Sample flow rate	ml/s	None	None
Temp/Pressure(alter)	$^\circ$C $\times$ 10/pascal(alter)	None	None
Sampling period	raw float	None	None
Sum of the counts	raw integer	None	None
PM1	μg/m^3	None	None
PM2.5	μg/m^3	None	None
PM10	μg/m^3	None	None

4.5.2   Firmware

This parameter provides the Firmware version of the alpha sensor by unsigned 8-bit integer.

0x29	0x82	Raw values
Byte[0]	Byte[1]	Bytes[2 − 3]

Value	Board Output	Post-Processing Mode	Post-processed Output
Firmware version	raw integer	None	None

4.5.3   Configuration

This parameter provides various information as listed below. Since this configuration data is too long to fit into a sub-packet, the data seperated into four sections to be packed into four sub-packets. Thus each of sub-packet takes 64 Bytes in length.

- Bin Boundaries (BB0 - BB14) are unsinged 16 bit integer variables, and two spare bytes
  (Bytes[0 − 31] from Alpha sensor, Byte[2 − 33] on sub-packet A).

- Bin Particle Volumes (BPV0 - BPV15) are float variables occupyting 4 bytes each
  (Bytes[32 − 95] from Alpha sensor, Byte[34 − 65] on sub-packet A and Byte[2 − 33] on sub-packet B).

- Bin Particle Densities (BPD0 − BPD15) are float variables occupying 4 bytes each
  (Bytes[96 − 159] from Alpha sensor, Byte[34 − 65] on sub-packet B and Byte[2 − 33] on sub-packet C).

- Bin Sample Volume Weightings (BSVW0 − BSVW15) are float variables occupying 4 bytes each
  (Bytes[160 − 223] from Alpha sensor, Byte[34 − 65] on sub-packet C and Byte[2 − 33] on sub-packet D).

- Gain Scaling Coefficient (GSC) is float variable occupying 4 bytes
  (Bytes[224 − 227] from Alpha sensor, Byte[34 − 37] on sub-packet D).

- Sample flow rate is a float variable occupying 4 bytes
  (Bytes[228 − 231] from Alpha sensor, Byte[38 − 41] on sub-packet D).

- Laser DAC value is unsigned 8bit interger variable
  (Byte[232] from Alpha sensor, Byte[42] on sub-packet D).

- Fan DAC value is unsigned 8bit integer variable
  (Byte[233] from Alpha sensor, Byte[43] on sub-packet D).

- Time of Flight to Sample Flow Rate conversion factor is unsigned 8bit integer variable
  (Byte[234] from Alpha sensor, Byte[44] on sub-packet D).

- 21 spare bytes follow Configuration variables
  (Bytes[235 − 255] from Alpha sensor, Byte[45 − 65] on sub-packet D).

Source ID (0x30 ~ 0x33)	0xC0	Raw values
Byte[0]	Byte[1]	Bytes [2 − 65]

Value	Board Output	Post-Processing Mode	Post-processed Output
Configuration Packet A (Source ID 0x30)			
Bin Boundaries (32 Bytes)	raw integer	None	None
Bin Particle Volumes A (32 Bytes)	raw float	None	None
Configuration Packet B (Source ID 0x31)			
Bin Particle Volumes B (32 Bytes)	raw float	None	None
Bin Particle Densities A (32 Bytes)	raw float	None	None
Configuration Packet C (Source ID 0x32)			
Bin Particle Densities B (32 Bytes)	raw float	None	None
Bin Sample Volume Weightings A (32 Bytes)	raw float	None	None
Configuration Packet D (Source ID 0x33)			
Bin Sample Volume Weightings B (32 Bytes)	raw float	None	None
Gain Scaling Coefficient (4 Bytes)	raw float	None	None
Sample Flow Rate (4 Bytes)	raw float	None	None
Laser DAC (1 Byte)	raw integer	None	None
Fan DAC (1 Byte)	raw integer	None	None
Conversion factor (1 Byte)	raw integer	None	None
Spare Bytes	None (21 Byte)	None	None

5 Sensor Data Units

5.1 Raw and Processed

Table 5: Sensor units both in raw and processed format

Sensor/Parameter	Raw Units	Processed Units	Comments
Airsense board			
Air/Lightsense MAC	No Units	No Units	
TMP112	°C	°C	
HTU21D	°C, %RH	°C, %RH	
HIH4030	%RH	%RH	
BMP180	°C, Pa	°C, Pa	
PR103J2	integer	°C	
TSL250RD	integer	μw/m^2	
MMA8452Q	g, g, g, g	g, g, g, g	
SPV1840LR5H-B			which pin does the sensor is using?
TSYS01	°C	°C	
Lightsense board			
HMC5883L	G, G, G	G, G, G	
HIH6130	°C, %RH	°C, %RH	
APDS-9006-020	integer	lux	
TSL260RD	integer	μw/m^2	
TSL250RD	integer	μw/m^2	
MLX75305	integer	μw/m^2	
ML8511	integer	μw/m^2	
TMP421	°C	°C	
Chemsense board			
Total reducing gases			
Nitrogen dioxide			
Ozone			
Hydrogen sulphide			
Total oxidizing gases			
Carbon monoxide			
Sulfur dioxide			
Sensirion (SHT25)	100ths of °C, 100ths of %RH	°C, %RH	
LPS25H	100ths of °C, Pa	°C, Pa	
Si1145	fixed value		firmware is not completed
Intel MAC address	No Units	No Units	
			Continued on next page

Table 5 – continued from previous page

Sensor/Parameter	Raw Units	Processed Units	Comments
CO ADV temp	100ths of °C	°C	
IAQ IRR ADC temp	100ths of °C	°C	
O3 NO2 ADC temp	100ths of °C	°C	
SO2 H2S ADC temp	100ths of °C	°C	
CO LMP temp	100ths of °C	°C	
Accelerometer			
Gyro			
Alpha sensor			
Histogram			
Firmware			
Configuration			

5.2   conversion processure

5.3   Airsense:

5.3.1   TMP112

Raw ouput of TMP112 is a digital 12-bit value. Coresensor firmware calculates temperature in centigrade using 12-bits of two Bytes reading of the sensor output.

$$\text{temperature } (°C) = \text{usigned integer form of 12-bit digital output} \times 0.0625$$

The equation refers the resolution for the Temperature ADC in Internal Temperature mode which is 0.0625 $°C/count$.

5.3.2   HTU21D

Raw output values of HTU21D are digital 12-bits / 8-bits (for Temperature / relative humidity) from default configuration. Coresensor firmware calculates temperature and humidity in centigrade and relative humidity using relevant bits of two Bytes reading of the sensor output.

$$\text{temperature } (°C) = \frac{\text{usigned integer form of digital output}}{2^{16}} \times 175.72 - 46.85$$

$$\text{humidity } (\%RH) = \frac{\text{usigned integer form of digital output}}{2^{16}} \times 125 - 6$$

The calculated humidity is re-calculated in sensor plugin using temperature coefficient compensation equation.

$$\text{humidity } (\%RH) = \text{unsigned integer form of - (25 - temperature)} \times 0.15$$

The equation refers temperature coefficient of the HTU21D(F) in 0.15 $\%RH/°C$.

5.3.3   HIH4030

Raw output of HIH4030 is an interger indicating output voltage from the sensor which is mapped into an integer value between 0 and 1023. Output voltages between 0 and 5 volts from the sensor will be mapped into integer values between 0 and 1023. Coresensor firmware delivers the two Bytes of raw integer value, and coresense plugin calculates humidity using output voltage from the sensor.

$$\text{output voltage } (V) = \frac{\text{usinged integer raw output} \times 5}{1023}$$

$$\text{humidity } (\%RH) = (\text{output voltage} - 0.85) \times \frac{100}{3}$$

The slope term ($\frac{100}{3}$) and y-intercept (0.85) are comming from a graph given in the HIH4030 sensor datasheet (figure 4). This slope and y-intercept can be different depending on temperature.

5.3.4   BMP180

Raw ouput values of BMP180 are 16-bit/24-bit value (temperature/pressure), and the values are post-processed through a library provided by Adafruit Industries. Sensor output values from the coresensor firmware are temperature in centigrade and barometric pressure in pascal.

5.3.5   PR103J2

Raw output of PR103J2 is an interger indicating output voltage from the sensor which is mapped into integer values between 0 and 1023. Output voltages between 0 and 5 volts from the sensor will be mapped into integer values between 0 and 1023. Coresensor firmware delivers the two Bytes of raw integer value, and coresensor plugin calculates temperature using output voltage from the sensor and resistance-temperature look-up table (PR103J2 R-T table).

$$\text{output voltage } (V) = \frac{\text{usinged integer raw output} \times 5}{1023}$$

$$\text{resistance } (\Omega) = 47000 \times \left(\frac{1023}{\text{voltage}} - 1 \right)$$

5.3.6   TSL250RD

What we can get from TSL250RD in airsense board as a raw output is an interger indicating output voltage from the sensor which is mapped into integer values between 0 and 1023. Output voltages between 0 and 5 volts from the sensor will be mapped into integer values between 0 and 1023. Coresensor firmware delivers the two Bytes of raw integer value, and coresensor plugin calculates irradiance of visible light in micro-watt per square meter.

$$\text{output voltage } (V) = \frac{\text{usinged integer raw output} \times 5}{1023}$$

$$\text{irradiance } (\mu W/m^2) = \frac{\text{output voltage} - 0.09}{0.064}$$

The equation refers irradiance responsivity of TSL250RD which is 0.064 $mV/(\mu W/cm^2)$, and 0.09 is output voltage of dark condition which is initial offset (without any light − NEED TO BE CHECKED).

5.3.7   MMA8452Q

Raw ouput values of MMA8452Q are actual g value, this depends on scale being set.

5.3.8   SPV1840LR5H-B

5.3.9   TSYS01

Raw ouput value of TSYS01 is post-processed value through a library provided by Free Software Foundation, Inc.. Sensor output from the coresensor firmware is temperature in centigrade.

5.4   Lightsense:

5.4.1   HMC5883L

Raw ouput values of HMC5883L are post-processed values through a library provided by Adafruit Industries. Sensor output values from the coresensor firmware are acceleration values in Gauss.

5.4.2   HIH6130

Raw ouput values of HIH6130 are 14-bit temperature and humidity values. Coresensor firmware calculates temperature and humidity in centigrade and relative humidity using 14-bits of two Bytes reading of the sensor output.

$$\text{temperature (}^{\circ}\text{C)} = \frac{\text{usigned integer form of digital output}}{2^{14} - 2} \times 165 - 40$$

$$\text{humidity (\%RH)} = \frac{\text{usigned integer form of digital output}}{2^{14} - 2} \times 100$$

5.4.3   APDS-9006-020, TSL260RD, TSL250RD, MLX75305, ML8511 :
using MCP3426

Raw output value of MCP3426 is an digital output which is proportional to the input voltage and programmable gain amplifier (PGA) settings (see schematics v3.1). Default setting of PGA is x1, and we are using 16-bits resolution. Coresensor firmware delivers the two Bytes of raw integer value, and coresensor plugin calculates irradiance of light in micro-watt per square meter using voltage output from each sensor. The voltage value need to be calculated regarding to the airsense circuit schematics and output modification equation for MCP3426 circuit. Coresensor firmware delivers the two Bytes of raw integer value, and coresensor plugin calculates irradiance of visible light in a designated unit.

$$\text{output voltage of MCP3426 (}V\text{)} = \frac{\text{unsigned integer form of digital output}}{\text{maximum 16-bit code} + 1} * \text{reference voltage}$$

$$\text{input voltage od MCP3426} = \frac{\text{output voltage of MCP3426} * 5}{2}$$

The equation refers maximum n-bit code which is $2^{n-1} - 1$, and in case of 16-bit code, the number is 32767. Also reference voltage of MCP3426 is $2.048\ V$. According to schematics v3.1, the output voltage from each sensor is divided, so the original output voltage can be calculated by the equation given above.

a. APDS-9006-020   Raw output value of APDS-9006-020 is an analog current which is proportional to the irradiance. The output current can be converted into voltage value according to the board schematics v3.1.

$$\text{output current (}\mu A\text{)} = \frac{\text{input voltage to MCP3426}}{0.005}$$

$$\text{irradiance (}lux\text{)} = \text{output current} - 0.000156 * 2.5$$

The equation refers resistance of $5\ K\Omega$ which is used as 0.005 to calculate current with unit μA as shown in schematics v3.1. Also initial offset of the sensor is applied as 0.000156, and linear relationship factor as 2.5, however these sensor property can be changed base on experiments.

b. TSL260RD   Raw output value of TSL260RD is an analog voltage which is inverse proportional to the irradiance. The output voltage from the sensor has been calculated though the equations given in section 5.4.3.

$$\text{irradiance (}\mu W/m^2\text{)} = \frac{\text{output current} - 0.005313}{0.058}$$

The equation refers irradiance responsivity of TSL260RD which is $0.058\ mV/(\mu W/cm^2)$, and 0.005313 is output voltage of dark condition, which is initial offset (without any light − NEED TO BE CHECKED).

c. TSL250RD   Raw output value of TSL250RD is an analog voltage which is inverse proportional to the irradiance. The output voltage from the sensor has been calculated though the equations given in section 5.4.3.

$$\text{irradiance } (\mu W/m^2) = \frac{\text{output current} - 0.005313}{0.064}$$

The equation refers irradiance responsivity of TSL250RD which is 0.064 $mV/(\mu W/cm^2)$, and 0.005313 is output voltage of dark condition, which is initial offset (without any light − NEED TO BE CHECKED).

d. MLX75305   Raw output value of MLX75305 is an analog voltage which is inverse proportional to the irradiance. The output voltage from the sensor has been calculated though the equations given in section 5.4.3.

$$\text{irradiance } (\mu W/m^2) = \frac{\text{output current} - 0.0996}{0.007}$$

The equation refers irradiance responsivity of MLX75305 which is 0.007 $mV/(\mu W/cm^2)$, and 0.0996 is output voltage of dark condition, which is initial offset (without any light − NEED TO BE CHECKED).

e. ML8511   Raw output value of ML8511 is an analog voltage which is proportional to the irradiance. The output voltage from the sensor has been calculated though the equations given in section 5.4.3.

$$\text{irradiance } (\mu W/m^2) = (\text{output current} - 1.489) * 12.49$$

The equation refers proportional factor which is 12.49 $mV/(\mu W/cm^2)$, and 0.0996 is output voltage of dark condition, which is initial offset (without any light − NEED TO BE CHECKED).

5.4.4   TMP421

Raw ouput value of TMP421 is 16-bit value, and the value is post-processed through a library provided by Free Software Foundation, Inc.. Sensor output from the coresensor firmware is temperature in centigrade.

5.5   Chemsense:

5.5.1   Chmical sensors

- Total reducing gases
- Nitrogen dioxide
- Ozone
- Hydrogen sulphide
- Total oxidizing gases
- Carbon monoxide
- Sulfur dioxide

5.5.2   SHT25

Raw output values of SHT25 through chemsense firmware are 100ths of temperature in centigrade and 100ths of humidity value.

$$\text{temperature } (^\circ C) = \frac{\text{output value}}{100}$$

$$\text{humidity } (\%RH) = \frac{\text{output value}}{100}$$

5.5.3   LPS25H

Raw output values of LPS25H through chemsense firmware are 100ths of temperature in centigrade and pressure in Pa.

$$\text{temperature } (^\circ C) = \frac{\text{output value}}{100}$$

5.5.4   Si1145

Si1145 is a light sensor, and Chemsense board firmware is not completed, so the fixed hex values need to be ignored (July 2016).

5.5.5   ADC Temperatures

Chemsense board measures temperature of sensor ADCs. All of them give ADC temperature in 100ths of degree celsious. This includes five parameters which are:

- CO ADC Temp
- IAQ/IRR ADC Temp
- O3/NO2 ADC Temp
- SO2/H2S ADC Temp
- CO CMT Temp

$$\text{temperature } (^\circ C) = \frac{\text{output value}}{100}$$

5.5.6   Accelerometer

5.5.7   Gyro

5.6   Alpha Sensor:

5.6.1   Histogram

5.6.2   Firmware

5.6.3   Configuration