ZMOD4510 Nitrogen Dioxide and Ozone Firmware Documentation

Firmware Version: 1.0.1

Contents

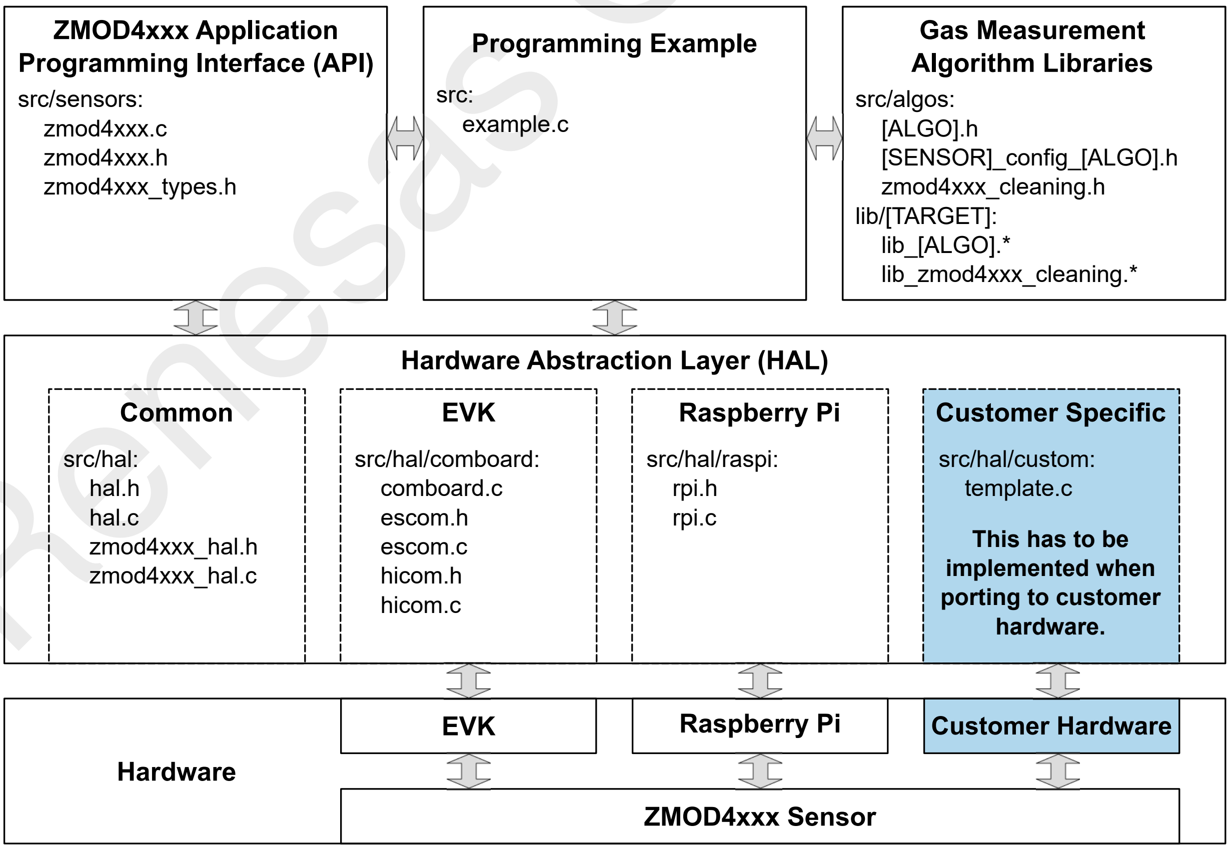
Chapter 1

Overview

This document describes the libraries for the ZMOD4510 gas sensor module using the Ozone and Nitrogen Dioxide algorithm for air quality measurements in ultra-low power mode (ULP). This algorithm is recommended for accurate and consistent ozone and nitrogen dioxide concentration as well as Air Quality Index (AQI) measurement.

The firmware package includes an example that can be compiled for the use with an EVK board which is connected to a host computer or for an Raspberry Pi. In addition an Arduino library is provided, that allows using the gas sensor on the Arduino MKRZERO.

The figure below shows an overview of the ZMOD4xxx API, programming example and libraries.



If required, the example can be adapted to run on customer specific hardware. For the adaption to the customer hardware, this firmware packages provides a HAL template in hal/custom/template.c. Please refer to the documentation of this file, and the HAL API documentation. Note that some of the HAL functions may not be required by specific sensors. Please refer to the *HAL API Requirements* section of the sensor you're trying to interface. Refer to the ZMOD4510 Programming Manual - Read Me for further information regarding sample code.

1.1 Folder Structure

- `src`: Source code directory, including a Makefile for below mentioned binaries
  - `sensors`: Headers and sources for different sensors
  - `hal`: Headers, sources and libraries for hardware abstraction
  - `algos`: Headers for algorithm and cleaning library
- `lib`: Precompiled algorithm libraries
- `doc`: Documentation
- `windows`: Pre-compiled example application for the EVK board on a 64-bit Windows platform
- `raspberrypi`: Pre-compiled example application for Raspberry-Pi, using the PiGPIO library
- `arduino`: Arduino library for installation in Arduino IDE (including fully working example code)

Note

Root privileges are required to execute the Raspbery-Pi example program.

Chapter 2

Module Index

2.1 Modules

Here is a list of all modules:

Chapter 3

File Index

3.1 File List

Here is a list of all documented files with brief descriptions:

Chapter 4

Module Documentation

4.1 Nitrogen Dioxide and Ozone Library API

Modules

- Return codes of the algorithm functions.

Files

- file no2_o3.h

  This file contains the data structure definitions and the function definitions for the NO2 O3 algorithm.

Functions

- int8_t init_no2_o3 (no2_o3_handle_t ∗handle)

  Initializes the NO2 O3 algorithm.
- int8_t calc_no2_o3 (no2_o3_handle_t ∗handle, const zmod4xxx_dev_t ∗dev, const no2_o3_inputs_t ∗algo_↩ input, no2_o3_results_t ∗results)

  calculates NO2 O3 results from present sample.

Data Structures

- struct algorithm_version

  Variables that describe the library version. More...
- struct no2_o3_handle_t

  Variables that describe the sensor or the algorithm state. More...
- struct no2_o3_results_t

  Variables that receive the algorithm outputs. More...
- struct no2_o3_inputs_t

  Variables that are needed for algorithm. More...

4.1.1 Detailed Description

4.1.2 Data Structure Documentation

4.1.2.1 struct algorithm_version

Variables that describe the library version.

Data Fields

- uint8_t **major**
- uint8_t **minor**
- uint8_t **patch**

4.1.2.2 struct no2_o3_handle_t

Variables that describe the sensor or the algorithm state.

Data Fields

- uint32_t sample_counter
- float **rmoxs_smooth** [4]
- float **logrmoxs_mean** [4]
- float **logrmoxs_var** [4]
- float **o3_1min_ppb**
- float **o3_1h_ppb**
- float **o3_8h_ppb**
- float **no2_1min_ppb**
- float **no2_1h_ppb**

4.1.2.2.1 Field Documentation

4.1.2.2.1.1 sample_counter

```
uint32_t sample_counter
```

Sample counter. Will saturate at 0xFFFFFFFF.

4.1.2.3 struct no2_o3_results_t

Variables that receive the algorithm outputs.

Data Fields

- float rmox [4]
- float temperature
- float O3_conc_ppb
- float NO2_conc_ppb
- uint16_t FAST_AQI
- uint16_t EPA_AQI

4.1.2.3.1 Field Documentation

4.1.2.3.1.1 EPA_AQI

```
uint16_t EPA_AQI
```

EPA_AQI stands for the Air Quality Index according to the EPA standard based on ozone.

4.1.2.3.1.2 FAST_AQI

```
uint16_t FAST_AQI
```

FAST_AQI stands for a 1-minute average of the Air Quality Index according to the EPA standard based on ozone

4.1.2.3.1.3 NO2_conc_ppb

```
float NO2_conc_ppb
```

NO2_conc_ppb stands for the NO2 concentration in part-per-billion

4.1.2.3.1.4 O3_conc_ppb

```
float O3_conc_ppb
```

O3_conc_ppb stands for the ozone concentration in part-per-billion

4.1.2.3.1.5 rmox

```
float rmox[4]
```

MOx resistance.

4.1.2.3.1.6 temperature

```
float temperature
```

Temperature (degC) used for ambient compensation

4.1.2.4 struct no2_o3_inputs_t

Variables that are needed for algorithm.

Parameters

in	*adc_result*	Value from read_adc_result function
in	*humidity_pct*	relative ambient humidity (%)
in	*temperature_degc*	ambient temperature (degC)

Data Fields

- uint8_t ∗ **adc_result**
- float **humidity_pct**
- float **temperature_degc**

4.1.3 Function Documentation

4.1.3.1 calc_no2_o3()

```
int8_t calc_no2_o3 (
            no2_o3_handle_t ∗ handle,
            const zmod4xxx_dev_t ∗ dev,
            const no2_o3_inputs_t ∗ algo_input,
            no2_o3_results_t ∗ results )
```

calculates NO2 O3 results from present sample.

Parameters

in	*handle*	Pointer to algorithm state variable.
in	*dev*	Pointer to the device.
in	*algo_input*	Structure containing inputs required for algo calculation.
out	*results*	Pointer for storing the algorithm results.

Returns

error code.

4.1.3.2 init_no2_o3()

```
int8_t init_no2_o3 (
            no2_o3_handle_t ∗ handle )
```

Initializes the NO2 O3 algorithm.

Parameters

`out`	*handle*	Pointer to algorithm state variable.

Returns

error code.

4.2 ZMOD4xxx Sensor API

Files

- file zmod4xxx.h

  zmod4xxx-API functions
- file zmod4xxx_types.h

  zmod4xxx types

Functions

- zmod4xxx_err zmod4xxx_calc_factor (zmod4xxx_conf ∗conf, uint8_t ∗hsp, uint8_t ∗config)

  Calculate measurement settings.
- float zmod4xxx_calc_single_rmox (zmod4xxx_dev_t ∗dev, uint8_t ∗adc_result)

  Calculate mox resistance from ADC raw data.
- zmod4xxx_err zmod4xxx_calc_rmox (zmod4xxx_dev_t ∗dev, uint8_t ∗adc_result, float ∗rmox)

  Calculate mox resistance on array of results.
- zmod4xxx_err zmod4xxx_check_error_event (zmod4xxx_dev_t ∗dev)

  Check the error event of the device.
- zmod4xxx_err zmod4xxx_init_measurement (zmod4xxx_dev_t ∗dev)

  Initialize the sensor for corresponding measurement.
- zmod4xxx_err zmod4xxx_init_sensor (zmod4xxx_dev_t ∗dev)

  Initialize the sensor after power on.
- zmod4xxx_err zmod4xxx_null_ptr_check (zmod4xxx_dev_t ∗dev)

  Check if all function pointers are assigned.
- zmod4xxx_err zmod4xxx_prepare_sensor (zmod4xxx_dev_t ∗dev)

  High-level function to prepare sensor.
- zmod4xxx_err zmod4xxx_read_adc_result (zmod4xxx_dev_t ∗dev, uint8_t ∗adc_result)

  Read adc values from the sensor.
- zmod4xxx_err zmod4xxx_read_rmox (zmod4xxx_dev_t ∗dev, uint8_t ∗adc_result, float ∗rmox)

  High-level function to read rmox.
- zmod4xxx_err zmod4xxx_read_sensor_info (zmod4xxx_dev_t ∗dev)

  Read sensor parameter.
- zmod4xxx_err zmod4xxx_read_status (zmod4xxx_dev_t ∗dev, uint8_t ∗status)

  Read the status of the device.
- zmod4xxx_err zmod4xxx_read_tracking_number (zmod4xxx_dev_t ∗dev, uint8_t ∗track_num)

  Read tracking number of sensor.
- zmod4xxx_err zmod4xxx_start_measurement (zmod4xxx_dev_t ∗dev)

  Start the measurement.
- zmod4xxx_err zmod4xxx_start_measurement_at (zmod4xxx_dev_t ∗dev, uint8_t step)

  Start the measurement at an user-defined sequencer step.

Data Structures

- struct zmod4xxx_conf_str

  A single data set for the configuration. More...
- struct zmod4xxx_conf

  Structure to hold the gas sensor module configuration. More...
- struct zmod4xxx_dev_t

  Device structure ZMOD4xxx. More...

Macros

- #define **ZMOD4XXX_ADDR_PID** (0x00)
- #define **ZMOD4XXX_ADDR_CONF** (0x20)
- #define **ZMOD4XXX_ADDR_PROD_DATA** (0x26)
- #define **ZMOD4XXX_ADDR_CMD** (0x93)
- #define **ZMOD4XXX_ADDR_STATUS** (0x94)
- #define **ZMOD4XXX_ADDR_TRACKING** (0x3A)
- #define **ZMOD4XXX_LEN_PID** (2)
- #define **ZMOD4XXX_LEN_CONF** (6)
- #define **ZMOD4XXX_LEN_TRACKING** (6)
- #define **HSP_MAX** (8)
- #define **RSLT_MAX** (32)
- #define STATUS_SEQUENCER_RUNNING_MASK (0x80)
- #define STATUS_SLEEP_TIMER_ENABLED_MASK (0x40)
- #define STATUS_ALARM_MASK (0x20)
- #define STATUS_LAST_SEQ_STEP_MASK (0x1F)
- #define STATUS_POR_EVENT_MASK (0x80)
- #define STATUS_ACCESS_CONFLICT_MASK (0x40)

Typedefs

- typedef int8_t(∗ zmod4xxx_i2c_ptr_t) (uint8_t addr, uint8_t reg_addr, uint8_t ∗data_buf, uint8_t len)

  function pointer type for i2c access
- typedef void(∗ zmod4xxx_delay_ptr_p) (uint32_t ms)

  function pointer to hardware dependent delay function

Enumerations

- enum zmod4xxx_err {
  ZMOD4XXX_OK = 0, ERROR_INIT_OUT_OF_RANGE, ERROR_GAS_TIMEOUT, ERROR_I2C = -3,
  ERROR_SENSOR_UNSUPPORTED, ERROR_CONFIG_MISSING, ERROR_ACCESS_CONFLICT, ERR↩
  OR_POR_EVENT,
  ERROR_CLEANING, ERROR_NULL_PTR }

  error_codes Error codes

4.2.1 Detailed Description

All ZMOD4xxx based gas sensing applications generate their results using algorithm libraries which are computing the desired result from raw data input that is delivered by the gas sensor. An overview of different algorithm implementations is given in *ZMOD4xxx Programming Manual - Read Me*. The raw sensor data is obtained through the ZMOD4xxx API. This API defines data structures and functions required to configure and operate the sensor. All of these functions work by accessing the sensor through its I2C interface.

As the sensor may be used in arbitrary hardware environments, the ZMOD4xxx API requires a hardware abstraction layer (HAL), providing access to hardware specific functions in a generic way. The HAL minimizes the effort to port a ZMOD4xxx application to a new platform (e.g. MCU). Only the HAL related files need to be provided.

An overview on the relation of the different sensor system components is given in the figure on the Overview section.

HAL API ports to a customer specific hardware require the following function pointers of the Interface_t HAL data structure to be initialized and working as documented:

Function Pointer	Required
i2cRead	**Mandatory**
i2cWrite	**Mandatory**
msSleep	**Mandatory**
reset	Not required

4.2.2 Data Structure Documentation

4.2.2.1 struct zmod4xxx_conf_str

A single data set for the configuration.

Data Fields

- uint8_t **addr**
- uint8_t **len**
- uint8_t ∗ **data_buf**

4.2.2.2 struct zmod4xxx_conf

Structure to hold the gas sensor module configuration.

Data Fields

- uint8_t **start**
- zmod4xxx_conf_str **h**
- zmod4xxx_conf_str **d**
- zmod4xxx_conf_str **m**
- zmod4xxx_conf_str **s**
- zmod4xxx_conf_str **r**
- uint8_t **prod_data_len**

4.2.2.3 struct zmod4xxx_dev_t

Device structure ZMOD4xxx.

Data Fields

- uint8_t i2c_addr
- uint8_t config [6]
- uint16_t mox_er
- uint16_t mox_lr
- uint16_t pid
- uint8_t ∗ prod_data
- zmod4xxx_i2c_ptr_t read
- zmod4xxx_i2c_ptr_t write
- zmod4xxx_delay_ptr_p delay_ms
- zmod4xxx_conf ∗ init_conf
- zmod4xxx_conf ∗ meas_conf

4.2.2.3.1 Field Documentation

4.2.2.3.1.1 config

`uint8_t config[6]`

configuration parameter set

4.2.2.3.1.2 delay_ms

`zmod4xxx_delay_ptr_p delay_ms`

function pointer to delay function

4.2.2.3.1.3 i2c_addr

`uint8_t i2c_addr`

i2c address of the sensor

4.2.2.3.1.4 init_conf

`zmod4xxx_conf* init_conf`

pointer to the init configuration

4.2.2.3.1.5 meas_conf

`zmod4xxx_conf* meas_conf`

pointer to the measurement configuration

4.2.2.3.1.6 mox_er

`uint16_t mox_er`

sensor specific parameter

4.2.2.3.1.7 mox_lr

`uint16_t mox_lr`

sensor specific parameter

4.2.2.3.1.8 pid

`uint16_t pid`

product id of the sensor

4.2.2.3.1.9 prod_data

```
uint8_t* prod_data
```

production data

4.2.2.3.1.10 read

```
zmod4xxx_i2c_ptr_t read
```

function pointer to i2c read

4.2.2.3.1.11 write

```
zmod4xxx_i2c_ptr_t write
```

function pointer to i2c write

4.2.3 Macro Definition Documentation

4.2.3.1 STATUS_ACCESS_CONFLICT_MASK

```
#define STATUS_ACCESS_CONFLICT_MASK (0x40)
```

AccessConflict

4.2.3.2 STATUS_ALARM_MASK

```
#define STATUS_ALARM_MASK (0x20)
```

Alarm

4.2.3.3 STATUS_LAST_SEQ_STEP_MASK

```
#define STATUS_LAST_SEQ_STEP_MASK (0x1F)
```

Last executed sequencer step

4.2.3.4 STATUS_POR_EVENT_MASK

```
#define STATUS_POR_EVENT_MASK (0x80)
```

POR_event

4.2.3.5 STATUS_SEQUENCER_RUNNING_MASK

```
#define STATUS_SEQUENCER_RUNNING_MASK (0x80)
```

Sequencer is running

4.2.3.6 STATUS_SLEEP_TIMER_ENABLED_MASK

```
#define STATUS_SLEEP_TIMER_ENABLED_MASK (0x40)
```

SleepTimer_enabled

4.2.4 Typedef Documentation

4.2.4.1 zmod4xxx_delay_ptr_p

```
typedef void(* zmod4xxx_delay_ptr_p) (uint32_t ms)
```

function pointer to hardware dependent delay function

Parameters

`in`	*delay*	in milliseconds

Returns

none

4.2.4.2 zmod4xxx_i2c_ptr_t

```
typedef int8_t(* zmod4xxx_i2c_ptr_t) (uint8_t addr, uint8_t reg_addr, uint8_t *data_buf, uint8←
_t len)
```

function pointer type for i2c access

Parameters

`in`	*addr*	7-bit I2C slave address of the ZMOD4xxx
`in`	*reg_addr*	address of internal register to read/write
`in,out`	*data*	pointer to the read/write data value
`in`	*len*	number of bytes to read/write

Returns

error code

Return values

0	success
!= 0	error

4.2.5 Enumeration Type Documentation

4.2.5.1 zmod4xxx_err

```
enum zmod4xxx_err
```

error_codes Error codes

Enumerator

ERROR_INIT_OUT_OF_RANGE	The initialization value is out of range.
ERROR_GAS_TIMEOUT	A previous measurement is running that could not be stopped or sensor does not respond.
ERROR_I2C	I2C communication was not successful.
ERROR_SENSOR_UNSUPPORTED	The Firmware configuration used does not match the sensor module.
ERROR_CONFIG_MISSING	There is no pointer to a valid configuration.
ERROR_ACCESS_CONFLICT	Invalid ADC results due to a still running measurement while results readout.
ERROR_POR_EVENT	Power-on reset event. Check power supply and reset pin.
ERROR_CLEANING	The maximum numbers of cleaning cycles ran on this sensor. Cleaning function has no effect anymore.
ERROR_NULL_PTR	The dev structure did not receive the pointers for I2C read, write and/or delay.

4.2.6 Function Documentation

4.2.6.1 zmod4xxx_calc_factor()

```
zmod4xxx_err zmod4xxx_calc_factor (
            zmod4xxx_conf * conf,
            uint8_t * hsp,
            uint8_t * config )
```

Calculate measurement settings.

Parameters

`in`	*conf*	measurement configuration data
`in`	*hsp*	heater set point pointer
`in`	*config*	sensor configuration data pointer

Returns

error code

Return values

0	success

4.2.6.2 zmod4xxx_calc_rmox()

```
zmod4xxx_err zmod4xxx_calc_rmox (
                zmod4xxx_dev_t * dev,
                uint8_t * adc_result,
                float * rmox )
```

Calculate mox resistance on array of results.

Note

This is not a generic function. Only use it if indicated in your example program flow. This function uses zmod4xxx_calc_single_rmox

Parameters

`in`	*dev*	pointer to the device
`in,out`	*adc_result*	pointer to the adc results
`in,out`	*rmox*	pointer to the rmox values

Returns

error code

Return values

0	success
!= 0	error

4.2.6.3 zmod4xxx_calc_single_rmox()

```
float zmod4xxx_calc_single_rmox (
            zmod4xxx_dev_t * dev,
            uint8_t * adc_result )
```

Calculate mox resistance from ADC raw data.

Note

This is not a generic function. Only use it if indicated in your example program flow.

Parameters

`in`	*dev*	pointer to the device
`in,out`	*adc_result*	pointer to the adc results

Returns

computed MOX resistance

4.2.6.4 zmod4xxx_check_error_event()

```
zmod4xxx_err zmod4xxx_check_error_event (
            zmod4xxx_dev_t * dev )
```

Check the error event of the device.

Parameters

`in`	*dev*	pointer to the device

Returns

error code

Return values

0	success
!= 0	error

4.2.6.5 zmod4xxx_init_measurement()

```
zmod4xxx_err zmod4xxx_init_measurement (
            zmod4xxx_dev_t * dev )
```

Initialize the sensor for corresponding measurement.

Parameters

in	*dev*	pointer to the device

Returns

error code

Return values

0	success
!= 0	error

Note

Before calling function, measurement data set has to be passed the dev->meas_conf

4.2.6.6 zmod4xxx_init_sensor()

```
zmod4xxx_err zmod4xxx_init_sensor (
            zmod4xxx_dev_t * dev )
```

Initialize the sensor after power on.

Parameters

in	*dev*	pointer to the device

Returns

error code

Return values

0	success
!= 0	error

Note

Before calling function, initialization data set has to be passed the dev->init_conf

4.2.6.7 zmod4xxx_null_ptr_check()

```
zmod4xxx_err zmod4xxx_null_ptr_check (
            zmod4xxx_dev_t * dev )
```

Check if all function pointers are assigned.

Parameters

`in`	*dev*	pointer to the device

Returns

error code

Return values

0	success
!= 0	error

4.2.6.8 zmod4xxx_prepare_sensor()

```
zmod4xxx_err zmod4xxx_prepare_sensor (
            zmod4xxx_dev_t * dev )
```

High-level function to prepare sensor.

Parameters

`in`	*dev*	pointer to the device

Returns

error code

Return values

0	success
!=0	error

4.2.6.9 zmod4xxx_read_adc_result()

```
zmod4xxx_err zmod4xxx_read_adc_result (
            zmod4xxx_dev_t * dev,
            uint8_t * adc_result )
```

Read adc values from the sensor.

Parameters

in	*dev*	pointer to the device
in,out	*adc_result*	pointer to the adc results

Returns

error code

Return values

0	success
!= 0	error

4.2.6.10 zmod4xxx_read_rmox()

```
zmod4xxx_err zmod4xxx_read_rmox (
            zmod4xxx_dev_t * dev,
            uint8_t * adc_result,
            float * rmox )
```

High-level function to read rmox.

Note

This is not a generic function. Only use it if indicated in your example program flow.

Parameters

in	*dev*	pointer to the device
in,out	*adc_result*	pointer to the adc results
in,out	*rmox*	pointer to the rmox values

Returns

error code

Return values

0	success
!= 0	error

4.2.6.11 zmod4xxx_read_sensor_info()

```
zmod4xxx_err zmod4xxx_read_sensor_info (
             zmod4xxx_dev_t * dev )
```

Read sensor parameter.

Parameters

in	*dev*	pointer to the device

Returns

error code

Return values

0	success
!= 0	error

Note

This function must be called once before running other sensor functions.

4.2.6.12 zmod4xxx_read_status()

```
zmod4xxx_err zmod4xxx_read_status (
             zmod4xxx_dev_t * dev,
             uint8_t * status )
```

Read the status of the device.

Parameters

`in`	*dev*	pointer to the device
`in,out`	*status*	pointer to the status variable

Returns

error code

Return values

0	success
!= 0	error

4.2.6.13 zmod4xxx_read_tracking_number()

```
zmod4xxx_err zmod4xxx_read_tracking_number (
            zmod4xxx_dev_t * dev,
            uint8_t * track_num )
```

Read tracking number of sensor.

Note

The buffer pointed to by track_num must be at least 6 bytes long

Parameters

`in`	*dev*	pointer to the device
`in,out`	*track_num*	pointer to buffer to store the tracking number

Returns

error code

Return values

0	success
!= 0	error

4.2.6.14 zmod4xxx_start_measurement()

```
zmod4xxx_err zmod4xxx_start_measurement (
            zmod4xxx_dev_t * dev )
```

Start the measurement.

Parameters

in	*dev*	pointer to the device

Returns

error code

Return values

0	success
!= 0	error

4.2.6.15 zmod4xxx_start_measurement_at()

```
zmod4xxx_err zmod4xxx_start_measurement_at (
            zmod4xxx_dev_t * dev,
            uint8_t step )
```

Start the measurement at an user-defined sequencer step.

Parameters

in	*dev*	pointer to the device
in	*step*	sequencer step to start at

Returns

error code

Return values

0	success
!= 0	error

4.3 HiCom Board API

Files

- file hicom.h

  HiCom board type and function declarations.

Functions

- int HiCom_Find (HiComInterface_t ∗board, int ∗count)

  Enumerate HiCom boards Scans USB ports for connected HiCom boards.
- int HiCom_Connect (HiComInterface_t ∗board)

  Connect a HiCom instance Tries to connect to an interface that has been discovered with HiCom_Find() previously.
- int HiCom_Disconnect (HiComInterface_t ∗board)

  Disconnect a HicomBoard.
- int HiCom_SetPower (HiComInterface_t ∗board, bool on)

  Switch sensor power supply on or off.
- int HiCom_I2CWrite (HiComInterface_t ∗board, uint8_t slAddr, uint8_t ∗wData1, int wSize1, uint8_t ∗wData2, int wSize2)
- int HiCom_I2CRead (HiComInterface_t ∗board, uint8_t slAddr, uint8_t ∗wData, int wSize, uint8_t ∗rData, int rSize)
- char const ∗ HiCom_GetErrorString (int error, int scope, char ∗buf, int bufLen)

Data Structures

- struct HiComInterface_t

Macros

- #define **HICOM_NAME** "Dual RS232-HS A"
- #define **HICOM_I2C_SPEED** 100000

Typedefs

- typedef FT_STATUS **HiComStatus_t**
- typedef FT_HANDLE **HiComHandle_t**

Enumerations

- enum **HiComErrorScope_t** { **iesFTDI** = 0x21 }

4.3.1 Detailed Description

4.3.2 Data Structure Documentation

4.3.2.1 struct HiComInterface_t

Data Fields

- FT_DEVICE_LIST_INFO_NODE **node**
- int **index**

4.3.3 Function Documentation

4.3.3.1 HiCom_Connect()

```
int HiCom_Connect (
            HiComInterface_t * board )
```

Connect a HiCom instance Tries to connect to an interface that has been discovered with HiCom_Find() previously.

Parameters

board	Pointer to HiCom board discovered by HiCom_Find()

Returns

int 0 on success, error code otherwise

4.3.3.2 HiCom_Disconnect()

```
int HiCom_Disconnect (
            HiComInterface_t * board )
```

Disconnect a HicomBoard.

Parameters

board	Pointer to HiCom board to be disconnected

Returns

int

4.3.3.3 HiCom_Find()

```
int HiCom_Find (
              HiComInterface_t * board,
              int * count )
```

Enumerate HiCom boards Scans USB ports for connected HiCom boards.

Parameters

board	pointer to a buffer storing board information
count	[in] maximum count of boards to be stored [out] actual number of boards stored

Returns

int 0 on success, error code otherwise

4.3.3.4 HiCom_GetErrorString()

```
char const* HiCom_GetErrorString (
              int error,
              int scope,
              char * buf,
              int bufLen )
```

Generate a descriptive error message

Parameters

in	*error*	Error code
in	*scope*	Error scope

Returns

Error string

4.3.3.5 HiCom_I2CRead()

```
int HiCom_I2CRead (
             HiComInterface_t * board,
             uint8_t slAddr,
             uint8_t * wData,
             int wSize,
             uint8_t * rData,
             int rSize )
```

HiCom implementation of HAL_t::i2cRead

4.3.3.6 HiCom_I2CWrite()

```
int HiCom_I2CWrite (
             HiComInterface_t * board,
             uint8_t slAddr,
             uint8_t * wData1,
             int wSize1,
             uint8_t * wData2,
             int wSize2 )
```

HiCom implementation of HAL_t::i2cWrite

4.3.3.7 HiCom_SetPower()

```
int HiCom_SetPower (
             HiComInterface_t * board,
             bool on )
```

Switch sensor power supply on or off.

Parameters

board	Pointer to HiCom board to be operated

Returns

int 0 on success, error code otherwise

4.4 HSxxxx Sensor API

API providing a unified interface for Renesas Humidity and Temperature sensors.

Modules

- HS4xxx Sensor API

  HS4xxx Temperature/Humidity Sensor API.
- HS3xxx Sensor API

  HS3xxx Temperature/Humidity Sensor API.

Files

- file hsxxxx.h

  Renesas humidity sensors (HS3xxx, HS4xxx) abstraction.

Functions

- int HSxxxx_Init (HSxxxx_t ∗sensor, Interface_t ∗hal)

  Initialize the sensor object.
- int HSxxxx_Measure (HSxxxx_t ∗sensor, HSxxxx_Results_t ∗results)

  Perform one temperature measurement.
- char const ∗ HSxxxx_Name (HSxxxx_t ∗sensor)

  Return the temperature/humidity sensor type name.

Data Structures

- struct HSxxxx_Results_t

  Data structure holding humidity/temperature results. More...
- struct HSxxxx_t

  Data structure holding information required for HSxxxx API operation. More...

4.4.1 Detailed Description

API providing a unified interface for Renesas Humidity and Temperature sensors.

The Renesas HS3xxx and HS4xxx are highly accurate, ultra-low power, fully calibrated relative humidity and temperature sensors. These sensors may be used as standalone sensors or used as companion sensor for humidity and temperature sensitive applications (e.g., for Renesas gas sensors).

The present API is provided as a unified interface to both of these sensor types.

HAL API ports to a customer specific hardware require the following function pointers of the Interface_t HAL data structure to be initialized and working as documented:

Function Pointer	Required
i2cRead	**Mandatory**
i2cWrite	**Mandatory**
msSleep	**Mandatory**
reset	Not required

4.4.2 Data Structure Documentation

4.4.2.1 struct HSxxxx_Results_t

Data structure holding humidity/temperature results.

Data Fields

- float temperature
- float humidity

4.4.2.1.1 Field Documentation

4.4.2.1.1.1 humidity

```
float humidity
```

Relative humidity

4.4.2.1.1.2 temperature

```
float temperature
```

Temperature value in degree Celsius

4.4.2.2 struct HSxxxx_t

Data structure holding information required for HSxxxx API operation.

Data Fields

- Interface_t ∗ interface
- uint8_t i2cAddress

4.4.2.2.1 Field Documentation

4.4.2.2.1.1 i2cAddress

```
uint8_t i2cAddress
```

I2C slave address of the HSxxxx sensor

4.4.2.2.1.2 interface

```
Interface_t* interface
```

Pointer to the hal object for physical communication

4.4.3 Function Documentation

4.4.3.1 HSxxxx_Init()

```
int HSxxxx_Init (
            HSxxxx_t * sensor,
            Interface_t * hal )
```

Initialize the sensor object.

This function tries searching for a HS4xxx sensor first, by accessing the corresponding I2C address. If no such sensor is found, the function searches for a HS3xxx.

The type of sensor being detected can be determined using the function HSxxxx_Name().

Parameters

sensor	Pointer to sensor object to be initialized.
hal	Pointer to hal object for physical communication.

Returns

int Error code

Return values

0	On success
other	On error

4.4.3.2 HSxxxx_Measure()

```
int HSxxxx_Measure (
             HSxxxx_t * sensor,
             HSxxxx_Results_t * results )
```

Perform one temperature measurement.

This function starts a temperature/humidity measurement and waits for the availability of the result before it returns.

Note

This function is implemented as blocking function. Thus while the measurement is ongoing no other code is executed. Depending on the sensor the bocking time may be multiple tens of milliseconds.

Parameters

sensor	Pointer to the sensor object to be used.
results	Pointer to data structure for result storage.

Returns

int Error code

Return values

0	On success
other	On error

4.4.3.3 HSxxxx_Name()

```
char const* HSxxxx_Name (
             HSxxxx_t * sensor )
```

Return the temperature/humidity sensor type name.

The function HSxxxx_Init can identify different types of temperature/ humidity sensors. This function may be used to determine the sensor type that has been identified. The identification is performed based on the sensors I2C address.

Parameters

sensor	Pointer to the sensor object to be queried.

Returns

int Error code

Return values

0	On success
other	On error

4.5 HS4xxx Sensor API

HS4xxx Temperature/Humidity Sensor API.

Files

- file hs4xxx.h

  HS4xxx sensor declarations.

Functions

- int HS4xxx_Init (HSxxxx_t ∗sensor, Interface_t ∗hal)

  Initialize the sensor object.
- int HS4xxx_ReadID (HSxxxx_t ∗sensor, uint32_t ∗id)

  Read the unique sensor ID of the HS4xxx.
- int HS4xxx_Measure (HSxxxx_t ∗sensor, HSxxxx_Results_t ∗results)

  Perform a temperature/humidity measurement cycle.
- int HS4xxx_MeasureHold (HSxxxx_t ∗sensor, HSxxxx_Results_t ∗results)

  Perform a temperature/humidity measurement cycle using hold mode.
- int HS4xxx_MeasureStart (HSxxxx_t ∗sensor)

  Start a temperature/humidity measurement cycle in non-hold mode.
- int HS4xxx_MeasureRead (HSxxxx_t ∗sensor, HSxxxx_Results_t ∗results)

  Read temperature/humidity results in non-hold mode.

Enumerations

- enum HS4xxx_ErrorCodes_t { hteHS4xxxCRCError = 1 }

  Error code definitions specific for the HS4xxx API.

4.5.1 Detailed Description

HS4xxx Temperature/Humidity Sensor API.

HS4xxx is a series of highly accurate, fully calibrated automotive-grade relative humidity and temperature sensors. HS4xxx sensors provide a CRC checksum for communication integrity checking and have different modes of operation.

The HS4xxx API provides convenient access to the sensor's temperature & humidity measurement capabilities.

4.5.2 Enumeration Type Documentation

4.5.2.1 HS4xxx_ErrorCodes_t

```
enum HS4xxx_ErrorCodes_t
```

Error code definitions specific for the HS4xxx API.

Enumerator

hteHS4xxxCRCError	Result CRC error

4.5.3 Function Documentation

4.5.3.1 HS4xxx_Init()

```
int HS4xxx_Init (
            HSxxxx_t * sensor,
            Interface_t * hal )
```

Initialize the sensor object.

This function tries accessing the HS4xxx I2C address using *hal* as hardware interface. On success, the sensor object is initialized and can be used afterwards. Otherwise, an error code is returned and the sensor object is not usable.

Note

The HS4xxx API requires that the HAL interface object has the Interface_t::i2cRead and Interface_t::i2cWrite members defined. In addition, HS4xxx_Measure() requires the Interface_t::msSleep member.

Parameters

sensor	Pointer to sensor object to be initialized
hal	Pointer to HAL object providing physical communication

Returns

int Error code

Return values

0	On success
other	On error

4.5.3.2 HS4xxx_Measure()

```
int HS4xxx_Measure (
            HSxxxx_t * sensor,
            HSxxxx_Results_t * results )
```

Perform a temperature/humidity measurement cycle.

This function starts a measurement cycle in non-hold mode, waits for the result to be available and reads it. If the checksum computation is correct the result is stored in the *results* data structure. Otherwise the contents of *results* is left unmodified and an error code is returned.

Note

Although the HS4xxx is able to perform the requested measurement with a single I2C transaction (refer to H↩S4xxx_MeasureHold), this function uses the HS4xxx_MeasureStart() and HS4xxx_MeasureRead() functions together with the Interface_t::msSleep function. This is to allow operation on a wider variety of I2C interfaces. HS4xxx_MeasureHold() requires a minimum of 200kHz I2C clock frequency which is not supported by all interfaces.

Parameters

sensor	Pointer to an initialized sensor object
results	Pointer to a data structure, to store results in

Returns

int Error code

Return values

0	On success
other	On error

4.5.3.3 HS4xxx_MeasureHold()

```
int HS4xxx_MeasureHold (
            HSxxxx_t * sensor,
            HSxxxx_Results_t * results )
```

Perform a temperature/humidity measurement cycle using hold mode.

This function reads temperature/humidity values from the HS4xxx in hold mode (Refer to the HS4xxx datasheet for an explanation of hold mode). If the checksum computation is correct the result is stored in the *results* data structure. Otherwise the contents of *results* is left unmodified and an error code is returned.

Note

For hold measurements, the I2C clock frequency must be at least 200kHz. Otherwise the result readout is unreliable.

Parameters

sensor	Pointer to an initialized sensor object
results	Pointer to a data structure, to store results in

Returns

int Error code

Return values

0	On success
other	On error

4.5.3.4 HS4xxx_MeasureRead()

```
int HS4xxx_MeasureRead (
             HSxxxx_t * sensor,
             HSxxxx_Results_t * results )
```

Read temperature/humidity results in non-hold mode.

This function reads the temperature/humidity results from a measurement that has been started through HS4xxx↵_MeasureStart() previously. If the checksum computation is correct the result is stored in the *results* data structure. Otherwise the contents of *results* is left unmodified and an error code is returned.

Parameters

sensor	Pointer to an initialized sensor object
results	Pointer to a data structure, to store results in

Returns

int Error code

Return values

0	On success
other	On error

4.5.3.5 HS4xxx_MeasureStart()

```
int HS4xxx_MeasureStart (
            HSxxxx_t * sensor )
```

Start a temperature/humidity measurement cycle in non-hold mode.

Parameters

sensor	Pointer to an initialized sensor object

Returns

int Error code

Return values

0	On success
other	On error

4.5.3.6 HS4xxx_ReadID()

```
int HS4xxx_ReadID (
            HSxxxx_t * sensor,
            uint32_t * id )
```

Read the unique sensor ID of the HS4xxx.

Parameters

sensor	Pointer to an initialized sensor object
id	Pointer buffer to store the ID

Returns

int Error code

Return values

0	On success
other	On error

4.6 HS3xxx Sensor API

HS3xxx Temperature/Humidity Sensor API.

Files

- file hs3xxx.h
  HS3xxx sensor declarations.

Functions

- int HS3xxx_Init (HSxxxx_t ∗sensor, Interface_t ∗hal)
  Initialize the sensor object.
- int HS3xxx_ReadID (HSxxxx_t ∗sensor, uint32_t ∗id)
  Read the unique sensor ID of the HS3xxx.
- int HS3xxx_Measure (HSxxxx_t ∗sensor, HSxxxx_Results_t ∗results)
  Execute a temperature/humidity measurement cycle.
- int HS3xxx_MeasureStart (HSxxxx_t ∗sensor)
  Start a temperature/humidity measurement cycle.
- int HS3xxx_MeasureRead (HSxxxx_t ∗sensor, HSxxxx_Results_t ∗results)
  Read temperature/humidity results.

Enumerations

- enum HS3xxx_ErrorCodes_t { hteStaleData = 1 }
  Error code definitions specific for the HS3xxx API.

4.6.1 Detailed Description

HS3xxx Temperature/Humidity Sensor API.

HS3xxx is a series of highly-accurate, fully-calibrated relative humidity and temperature sensors.

The HS3xxx API provides convenient access to the temperature & humidity measurement capabilities of the sensor.

4.6.2 Enumeration Type Documentation

4.6.2.1 HS3xxx_ErrorCodes_t

```
enum HS3xxx_ErrorCodes_t
```

Error code definitions specific for the HS3xxx API.

Enumerator

hteStaleData	Sensor reported stale data.

4.6.3 Function Documentation

4.6.3.1 HS3xxx_Init()

```
int HS3xxx_Init (
            HSxxxx_t * sensor,
            Interface_t * hal )
```

Initialize the sensor object.

This function tries accessing the HS3xxx I2C address using *hal* as hardware interface. On success, the sensor object is initialized and can be used afterwards. Otherwise, an error code is returned and the sensor object is not usable.

Note

The HS3xxx API requires that the HAL interface object has the Interface_t::i2cRead and Interface_t::i2cWrite members defined. In addition, HS3xxx_Measure() requires the Interface_t::msSleep member, however, the check for this function is done in HS3xxx_Measure() and not in HS3xxx_Init().

Parameters

sensor	Pointer to sensor object to be initialized
hal	Pointer to HAL object providing physical communication

Returns

int Error code

Return values

0	On success
other	On error

4.6.3.2 HS3xxx_Measure()

```
int HS3xxx_Measure (
            HSxxxx_t * sensor,
            HSxxxx_Results_t * results )
```

Execute a temperature/humidity measurement cycle.

This function starts a measurement cycle in non-hold mode, waits for the result to be available and reads it. This is a convenience function which calls HS3xxx_MeasureStart() and HS3xxx_MeasureRead() with a delay between both calls, to allow the sensor to complete its measurement.

Parameters

sensor	Pointer to an initialized sensor object
results	Pointer to a data structure, to store results in

Returns

int Error code

Return values

0	On success
other	On error

4.6.3.3 HS3xxx_MeasureRead()

```
int HS3xxx_MeasureRead (
            HSxxxx_t * sensor,
            HSxxxx_Results_t * results )
```

Read temperature/humidity results.

This function reads the temperature/humidity results from a measurement that has been started through HS3xxx_MeasureStart() previously.

Parameters

sensor	Pointer to an initialized sensor object
results	Pointer to a data structure, to store results in

Returns

int Error code

Return values

0	On success
other	On error

4.6.3.4 HS3xxx_MeasureStart()

```
int HS3xxx_MeasureStart (
            HSxxxx_t * sensor )
```

Start a temperature/humidity measurement cycle.

Parameters

sensor	Pointer to an initialized sensor object

Returns

int Error code

Return values

0	On success
other	On error

4.6.3.5 HS3xxx_ReadID()

```
int HS3xxx_ReadID (
            HSxxxx_t * sensor,
            uint32_t * id )
```

Read the unique sensor ID of the HS3xxx.

Parameters

sensor	Pointer to an initialized sensor object
id	Pointer buffer to store the ID

Returns

int Error code

Return values

0	On success
other	On error

4.7 Hardware Abstraction Layer API

Hardware abstraction layer (HAL) API, used by Renesas Environmental Sensor APIs to physically access the sensor.

Modules

- ComBoard HAL

  Renesas communication board HAL.
- Raspberry Pi HAL

  Renesas communication board HAL.
- Custom HAL Template

  Template file for customer specific HAL implementation.

Files

- file zmod4xxx_hal.h

  ZMOD4xxx specific hardware abstraction layer definitions.
- file hal.h

  Renesas Environmental Sensor HAL definitions.

Functions

- int zmod4xxx_init (zmod4xxx_dev_t ∗dev, Interface_t ∗hal)
- int HAL_Init (Interface_t ∗hal)

  Initialize hardware and populate Interface_t object.
- int HAL_Deinit (Interface_t ∗hal)

  Cleanup before program exit.
- void HAL_HandleError (int errorCode, void const ∗context)

  Error handling function.
- int HAL_SetError (int error, int scope, ErrorStringGenerator_t errStrFn)

  Function storing error information.
- char const ∗ HAL_GetErrorInfo (int ∗error, int ∗scope, char ∗str, int bufSize)

  Get detailed information for last error.
- char const ∗ HAL_GetErrorString (int error, int scope, char ∗str, int bufSize)

  Error string generator for HAL-scoped errors.

Data Structures

- struct Interface_t

  A structure of pointers to hardware specific functions. More...

Typedefs

- typedef int(∗ I2CImpl_t) (void ∗, uint8_t, uint8_t ∗, int, uint8_t ∗, int)

  Function pointer type defining signature of I2C functions.
- typedef char const ∗(∗ ErrorStringGenerator_t) (int, int, char ∗, int)

  Function type used for generation of error strings.

Enumerations

- enum GenericError_t { ecSuccess = 0, ecHALError = 0x100 }

  Error code definitions.
- enum ErrorScope_t { esSensor = 0x0000, esAlgorithm = 0x1000, esInterface = 0x2000, esHAL = 0x3000 }

  Success status code and error scopes.
- enum HALError_t {
  heNoInterface = 1, heNotImplemented, heI2CReadMissing, heI2CWriteMissing,
  heSleepMissing, heResetMissing }

  HAL scope error definitions.

4.7.1 Detailed Description

Hardware abstraction layer (HAL) API, used by Renesas Environmental Sensor APIs to physically access the sensor.

The HAL API is a generic API that is used by all Renesas types of Environmental Sensors. It defines the interface that the sensor API can use to access the sensor on an arbitrary hardware platform. Renesas provides HAL implementations for EVK boards, Raspberry PI and Arduino. In order to use a specific sensor API in the customer application, the customer must implement the HAL API for his hardware platform. For that purpose, the template file template.c is provided, which must be adapted to work on the customer hardware. Please refer to the comments in the template file and the documentation of the HAL API for details.

All HAL API related files are located in path src/hal and its subdirectories.

4.7.2 Data Structure Documentation

4.7.2.1 struct Interface_t

A structure of pointers to hardware specific functions.

Data Fields

- void ∗ handle
- I2CImpl_t i2cRead
- I2CImpl_t i2cWrite
- void(∗ msSleep)(uint32_t ms)
- int(∗ reset)(void ∗handle)

4.7.2.1.1 Field Documentation

4.7.2.1.1.1 handle

```
void* handle
```

handle to physical interface

4.7.2.1.1.2 i2cRead

```
I2CImpl_t i2cRead
```

Pointer to I2C read implementation

The read operation may be preceded by a write to the same slave address. The function accepts a pointer to the interface handle, the slave address of the device to communicate with and two pairs of buffer pointer and buffer length. The first pair of buffer pointer / buffer length defines the data to be written, the second pair provides the pointer to the buffer where received data is stored and how many bytes shall be read. If the length field of the first buffer is not zero, the implementation must send an I2C write condition on the bus, transfer the data and send a repeated start condition followed by the corresponding read condition on the bus. If the length parameter of the first buffer is zero, no write is generated and the read is started immediately. The transmission must be terminated with a stop condition on the bus.

4.7.2.1.1.3 i2cWrite

```
I2CImpl_t i2cWrite
```

Pointer to I2C write implementation

For convenience, the write operation accepts two pairs of buffer pointer and buffer length. This allows to transfer addresses or commands prior to data without the need to manually concatenate transmit data in a buffer. The implementation of this function must generate a start condition followed by the I2C slave address of the target device, followed by all data from both buffers. At the end of the transmission a stop bit must be generated on the bus.

4.7.2.1.1.4 msSleep

```
void( * msSleep) (uint32_t ms)
```

Pointer to delay function

An implementation must delay execution by the specified number of `ms`

4.7.2.1.1.5 reset

```
int( * reset) (void *handle)
```

Pointer to reset function

Implementation must pulse the reset pin

4.7.3 Typedef Documentation

4.7.3.1 ErrorStringGenerator_t

```
typedef char const*( * ErrorStringGenerator_t) (int, int, char *, int)
```

Function type used for generation of error strings.

Functions of this type may be passed to HAL_SetError() to generate meaningful descriptions of error conditions.

4.7.3.2 I2CImpl_t

```
typedef int( * I2CImpl_t) (void *, uint8_t, uint8_t *, int, uint8_t *, int)
```

Function pointer type defining signature of I2C functions.

This function pointer typedef is used in Interface_t objects to hold pointers to I2C implementations of read and write.

4.7.4 Enumeration Type Documentation

4.7.4.1 ErrorScope_t

```
enum ErrorScope_t
```

Success status code and error scopes.

Enumerator

esSensor	Sensor scope
esAlgorithm	Algorithm scope
esInterface	Interface scope
esHAL	HAL scope

4.7.4.2 GenericError_t

```
enum GenericError_t
```

Error code definitions.

Enumerator

ecSuccess	Operation completed successfully
ecHALError	Returned by sensor API if a HAL function failed. Specific information about the error can be obtained using the function HAL_GetErrorInfo().

4.7.4.3 HALError_t

```
enum HALError_t
```

HAL scope error definitions.

When sensors are initialized (e.g. init_hardware()), the hal objects is checked whether all HAL functions required by the sensor are provided. If a function is missing one of the errors from this enumeration is returned.

Enumerator

heNoInterface	There was no interface found
heNotImplemented	The requested function is not implemented
heI2CReadMissing	Interface_t::i2cRead not provided
heI2CWriteMissing	Interface_t::i2cWrite not provided
heSleepMissing	Interface_t::msSleep not provided
heResetMissing	Interface_t::reset not provided

4.7.5 Function Documentation

4.7.5.1 HAL_Deinit()

```
int HAL_Deinit (
            Interface_t * hal )
```

Cleanup before program exit.

This function shall free up resources that have been allocated through HAL_Init().

Parameters

hal	pointer to Interface_t object to be deinitialized

Returns

error code

Return values

0	on success
!=0	in case of error

4.7.5.2 HAL_GetErrorInfo()

```
char const* HAL_GetErrorInfo (
            int * error,
            int * scope,
            char * str,
            int bufSize )
```

Get detailed information for last error.

Use this function in the error handler to obtain information about the last error code and which component generated it. In addition if an error string generator function was provided during error generation, this function may return a text string, describing the error in more detail.

Parameters

error	Pointer to integer, where the error code is written
scope	Pointer to integer, where the error scope (module that was generating the error is written)
str	Pointer to string buffer, where error message is written. If no string information is required, pass NULL pointer.
bufSize	Size of the string buffer, pass 0 if not used

Returns

Value passed in str

4.7.5.3 HAL_GetErrorString()

```
char const* HAL_GetErrorString (
            int error,
            int scope,
            char * str,
            int bufSize )
```

Error string generator for HAL-scoped errors.

This function generates error information for HAL scoped errors. Usually user code does not need to use this function directly.

Parameters

error	Error code for which error information is to be returned
scope	Error scope for which error information is to be returned
str	Pointer to string buffer, where error message is written
bufSize	Size of the string buffer

Returns

Value passed in str

4.7.5.4 HAL_HandleError()

```
void HAL_HandleError (
             int errorCode,
             void const * context )
```

Error handling function.

The implementation of this function defines the behavior of the application code when an error occurs during execution.

Parameters

errorCode	code of the error to be handled
context	additional context information

4.7.5.5 HAL_Init()

```
int HAL_Init (
             Interface_t * hal )
```

Initialize hardware and populate Interface_t object.

Any implementation must initialize those members of the Interface_t object that are required by the sensor being operated with pointers to functions that implement the behavior as specified in the Interface_t member documentation.

Parameters

hal	pointer to Interface_t object to be initialized

Returns

error code

Return values

0	on success
!=0	in case of error

4.7.5.6 HAL_SetError()

```
int HAL_SetError (
             int error,
             int scope,
             ErrorStringGenerator_t errStrFn )
```

Function storing error information.

The sensor interface has different components which may generate error conditions. To keep the sensor interface as simple as possible, this function is called in case of an error. The return value of this function will be returned as error code of the function in which an error has occurred.

Internally, this function stores the error code and the scope of the error (that is which module was generating the error) in a data structure. For all errors which do not have the scope esSensor, this function will return the generic error code ecHALError. Error codes generated by the sensor are returned directly.

It is possible to pass an error string generator function along with the error information. If this function is provided, the error handler can query an error string, providing more meaningful error information.

Parameters

error	An error code
scope	The scope of the error (integer identifying a module)
errStrFn	Optional function pointer that can decode generate a meaningful message for the error code. Pass NULL if not used.

4.7.5.7 zmod4xxx_init()

```
int zmod4xxx_init (
                zmod4xxx_dev_t * dev,
                Interface_t * hal )
```

Find the sensor and initialize hal specific data

If example code is ported to the customer platform, this function must be re-implemented. The function must assign the zmod4xxx_dev_t::read, zmod4xxx_dev_t::write and zmod4xxx_dev_t::delay_ms members of *dev*.

Parameters

in	*dev*	pointer to the sensor object
in	*hal*	pointer to the hal interface object

Returns

error code

Return values

0	on success
!=0	hardware specific error code

4.8 ComBoard HAL

Renesas communication board HAL.

Modules

- HiCom Board API
- ESCom Board API

4.8.1 Detailed Description

Renesas communication board HAL.

The ComBoard HAL is used to provide access to Renesas Environmental Sensors through a communication board that is connected to the users PC. The ComBoard HAL supports both, the new ESCom board and the old HiCom board. Some sensors might not be working with the HiCom board, as this board does not support clock stretching.

The ComBoard HAL is implemented in file src/hal/comboard/comboard.c. The HAL functions use the ESCom Board API and HiCom Board API to discover connected communication boards and initialize the Interface_t hal object function pointers appropriately to operate the sensor.

4.9 Raspberry Pi HAL

Renesas communication board HAL.

Files

- file rpi.h

  Raspberry PI HAL type and function declarations.

Enumerations

- enum **RPiErrorDefs_t** { **resPiGPIO** = 0x310000, **resI2C** = 0x320000, **recI2CLenMismatch** = 0x320001 }

4.9.1 Detailed Description

Renesas communication board HAL.

The Raspberry Pi HAL is used to provide access to Renesas Environmental Sensors through the GPIO pins of a Raspberry Pi. The HAL functions are implemented in file src/hal/raspi/rpi.c.

4.10 Custom HAL Template

Template file for customer specific HAL implementation.

Template file for customer specific HAL implementation.

The file src/hal/custom/template.c serves as a starting point for customers to implement a HAL for their own target hardware. Refer to the file documentation for instructions on how to implement the required HAL functionality and use the implementations of the Raspberry Pi HAL or the ComBoard HAL as further reference.

4.11 ESCom Board API

Files

- file escom.h

  ESCom board type and function declarations.

Functions

- int ESCom_Find (ESComInterface_t ∗boards, int ∗count)
- int ESCom_Connect (ESComInterface_t ∗board)
- int ESCom_Disconnect (ESComInterface_t ∗board)
- int ESCom_SetPower (ESComInterface_t ∗board, bool on)
- int ESCom_I2CWrite (ESComInterface_t ∗board, uint8_t slAddr, uint8_t ∗wData1, int wSize1, uint8_t ∗wData2, int wSize2)
- int ESCom_I2CRead (ESComInterface_t ∗board, uint8_t slAddr, uint8_t ∗wData, int wSize, uint8_t ∗rData, int rSize)
- int ESCom_GetSensorVoltage (ESComInterface_t ∗board, float ∗voltage)
- char const ∗ ESCom_GetErrorString (int error, int scope, char ∗buf, int bufLen)

Data Structures

- struct ESComInterface_t

Enumerations

- enum ESComErrorScope_t { **iesLibUSB** = 0x11, **iesI2C** = 0x12, **iesCommand** = 0x14 }
- enum **ESComMode_t** { **emUSB**, **emEVK** }

4.11.1 Detailed Description

4.11.2 Data Structure Documentation

4.11.2.1 struct ESComInterface_t

Data structure containing ESCom board information

Data Fields

- libusb_device ∗ **device**
- libusb_device_handle ∗ **handle**
- uint8_t **outEP**
- uint8_t **inEP**
- wchar_t **serial** [33]

4.11.3 Enumeration Type Documentation

4.11.3.1 ESComErrorScope_t

```
enum ESComErrorScope_t
```

ESCom error scopes

These codes identify the component that generated an error code

4.11.4 Function Documentation

4.11.4.1 ESCom_Connect()

```
int ESCom_Connect (
            ESComInterface_t * board )
```

Connect ESCom board

This function tries to connect the ESCom board identified by `board` and allocates the required resources.

Parameters

in	*board*	Pointer to an ::EScomInterface_t instance obtained through ESCom_Find()

Returns

0 on success or error code on failure

4.11.4.2 ESCom_Disconnect()

```
int ESCom_Disconnect (
            ESComInterface_t * board )
```

Disconnect ESCom board and free associated resources

Parameters

in	*board*	Pointer to an ::EScomInterface_t instance

Returns

0 on success or error code on failure

4.11.4.3 ESCom_Find()

```
int ESCom_Find (
             ESComInterface_t * boards,
             int * count )
```

Enumerate ESCom boards connected to PC

Scan available USB interfaces and save those with matching VID/PID in the `boards` buffer. Value pointed to by `count` serves as input and output. As input, `count` specifies the size maximum number of boards to be stored in `boards`. The buffer must provide sufficient space. Before return, this function stores the number of detected EScom boards in *count*.

Parameters

`in`	*boards*	Pointer to ESComInterface_t objects
`in,out`	*count*	Maximum number of boards to be stored in `board` [in], actual number of boards stored in `board` [out]

Returns

0 on success or error code on failure

4.11.4.4 ESCom_GetErrorString()

```
char const* ESCom_GetErrorString (
             int error,
             int scope,
             char * buf,
             int bufLen )
```

Generate a descriptive error message

Parameters

`in`	*error*	Error code
`in`	*scope*	Error scope

Returns

Error string

4.11.4.5 ESCom_GetSensorVoltage()

```
int ESCom_GetSensorVoltage (
            ESComInterface_t * board,
            float * voltage )
```

Read out the measured sensor voltage

Parameters

in	*board*	Pointer to an ::ESComInsteface_t instance
out	*voltage*	voltage value measured by ESCom board

4.11.4.6 ESCom_I2CRead()

```
int ESCom_I2CRead (
            ESComInterface_t * board,
            uint8_t slAddr,
            uint8_t * wData,
            int wSize,
            uint8_t * rData,
            int rSize )
```

This is the ESCom implementation of HAL_t::i2cRead

4.11.4.7 ESCom_I2CWrite()

```
int ESCom_I2CWrite (
            ESComInterface_t * board,
            uint8_t slAddr,
            uint8_t * wData1,
            int wSize1,
            uint8_t * wData2,
            int wSize2 )
```

This is the ESCom implementation of HAL_t::i2cWrite

4.11.4.8 ESCom_SetPower()

```
int ESCom_SetPower (
            ESComInterface_t * board,
            bool on )
```

Switch on or off the internal sensor supply voltage

Parameters

`in`	*board*	Pointer to an ::ESComInsteface_t instance obtained
`in`	*on*	Boolean indicating whether the sensor supply voltage shall be switched on

Returns

0 on success or error code otherwise

4.12 Return codes of the algorithm functions.

Macros

- #define NO2_O3_OK (0)
- #define NO2_O3_STABILIZATION (1)
- #define NO2_O3_DAMAGE (-102)

4.12.1 Detailed Description

4.12.2 Macro Definition Documentation

4.12.2.1 NO2_O3_DAMAGE

```
#define NO2_O3_DAMAGE (-102)
```

sensor damaged

4.12.2.2 NO2_O3_OK

```
#define NO2_O3_OK (0)
```

everything okay

4.12.2.3 NO2_O3_STABILIZATION

```
#define NO2_O3_STABILIZATION (1)
```

sensor in stabilization

Chapter 5

File Documentation

5.1 algos/no2_o3.h File Reference

This file contains the data structure definitions and the function definitions for the NO2 O3 algorithm.

Data Structures

- struct algorithm_version
  Variables that describe the library version. More...
- struct no2_o3_handle_t
  Variables that describe the sensor or the algorithm state. More...
- struct no2_o3_results_t
  Variables that receive the algorithm outputs. More...
- struct no2_o3_inputs_t
  Variables that are needed for algorithm. More...

Macros

- #define NO2_O3_OK (0)
- #define NO2_O3_STABILIZATION (1)
- #define NO2_O3_DAMAGE (-102)

Functions

- int8_t init_no2_o3 (no2_o3_handle_t ∗handle)
  Initializes the NO2 O3 algorithm.
- int8_t calc_no2_o3 (no2_o3_handle_t ∗handle, const zmod4xxx_dev_t ∗dev, const no2_o3_inputs_t ∗algo_←input, no2_o3_results_t ∗results)
  calculates NO2 O3 results from present sample.

5.2 algos/zmod4510_config_no2_o3.h File Reference

This is the configuration for ZMOD4510 module - no2_o3 library.

Macros

- #define **INIT** 0
- #define **MEASUREMENT** 1
- #define **ZMOD4510_PID** 0x6320
- #define **ZMOD4510_I2C_ADDR** 0x33
- #define **ZMOD4510_PROD_DATA_LEN** 10
- #define **ZMOD4510_ADC_DATA_LEN** (32)
- #define **ZMOD4510_NO2_O3_SAMPLE_TIME** (6000U)
- #define **ZMOD4XXX_H_ADDR** 0x40
- #define **ZMOD4XXX_D_ADDR** 0x50
- #define **ZMOD4XXX_M_ADDR** 0x60
- #define **ZMOD4XXX_S_ADDR** 0x68
- #define **RMOX3_OFFSET** (15 ∗ 2)

Variables

- uint8_t **data_set_4510_init** [ ]
- uint8_t **data_set_4510_no2_o3** [ ]
- zmod4xxx_conf **zmod_no2_o3_sensor_cfg** [ ]

5.2.1 Variable Documentation

5.2.1.1 data_set_4510_init

```
uint8_t data_set_4510_init[ ]
```

Initial value:

```
= {
                                    0x00, 0x50,
                                    0x00, 0x28, 0xC3, 0xE3,
                                    0x00, 0x00, 0x80, 0x40}
```

5.2.1.2 data_set_4510_no2_o3

```
uint8_t data_set_4510_no2_o3[]
```

Initial value:

```
= {
                                0x00, 0x50, 0xFF, 0x06,
                                0xFE, 0xA2, 0xFE, 0x3E,
                                0x00, 0x10, 0x00, 0x52,
                                0x3F, 0x66, 0x00, 0x42,
                                0x23, 0x03,
                                0x00, 0x00, 0x02, 0x41,
                                0x00, 0x41, 0x00, 0x41,
                                0x00, 0x49, 0x00, 0x50,
                                0x02, 0x42, 0x00, 0x42,
                                0x00, 0x42, 0x00, 0x4A,
                                0x00, 0x50, 0x02, 0x43,
                                0x00, 0x43, 0x00, 0x43,
                                0x00, 0x43, 0x80, 0x5B,
                                }
```

5.2.1.3 zmod_no2_o3_sensor_cfg

```
zmod4xxx_conf zmod_no2_o3_sensor_cfg[]
```

Initial value:

```
= {
    [INIT] = {
        .start = 0x80,
        .h = { .addr = ZMOD4XXX_H_ADDR, .len = 2, .data_buf = &data_set_4510_init[0]},
        .d = { .addr = ZMOD4XXX_D_ADDR, .len = 2, .data_buf = &data_set_4510_init[2]},
        .m = { .addr = ZMOD4XXX_M_ADDR, .len = 2, .data_buf = &data_set_4510_init[4]},
        .s = { .addr = ZMOD4XXX_S_ADDR, .len = 4, .data_buf = &data_set_4510_init[6]},
        .r = { .addr = 0x97, .len = 4},
    },

    [MEASUREMENT] = {
        .start = 0x80,
        .h = {.addr = ZMOD4XXX_H_ADDR, .len = 8, .data_buf = &data_set_4510_no2_o3[0]},
        .d = {.addr = ZMOD4XXX_D_ADDR, .len = 8, .data_buf = &data_set_4510_no2_o3[8]},
        .m = {.addr = ZMOD4XXX_M_ADDR, .len = 2, .data_buf = &data_set_4510_no2_o3[16]},
        .s = {.addr = ZMOD4XXX_S_ADDR, .len = 32, .data_buf = &data_set_4510_no2_o3[18]},
        .r = {.addr = 0x97, .len = 32},
        .prod_data_len = ZMOD4510_PROD_DATA_LEN,
    },
}
```

5.3 algos/zmod4xxx_cleaning.h File Reference

This file contains the cleaning function definition for ZMOD4xxx.

Functions

- int8_t zmod4xxx_cleaning_run (zmod4xxx_dev_t ∗dev)

  Start a cleaning procedure.

5.3.1 Function Documentation

5.3.1.1 zmod4xxx_cleaning_run()

```
int8_t zmod4xxx_cleaning_run (
            zmod4xxx_dev_t * dev )
```

Start a cleaning procedure.

Parameters

in	*dev*	pointer to the device

Returns

Error code

Return values

0	Success
!= 0	Error

5.4 hal/comboard/escom.h File Reference

ESCom board type and function declarations.

Data Structures

- struct ESComInterface_t

Enumerations

- enum ESComErrorScope_t { **iesLibUSB** = 0x11, **iesI2C** = 0x12, **iesCommand** = 0x14 }
- enum **ESComMode_t** { **emUSB**, **emEVK** }

Functions

- int ESCom_Find (ESComInterface_t ∗boards, int ∗count)
- int ESCom_Connect (ESComInterface_t ∗board)
- int ESCom_Disconnect (ESComInterface_t ∗board)
- int ESCom_SetPower (ESComInterface_t ∗board, bool on)
- int ESCom_I2CWrite (ESComInterface_t ∗board, uint8_t slAddr, uint8_t ∗wData1, int wSize1, uint8_t ∗wData2, int wSize2)
- int ESCom_I2CRead (ESComInterface_t ∗board, uint8_t slAddr, uint8_t ∗wData, int wSize, uint8_t ∗rData, int rSize)
- int ESCom_GetSensorVoltage (ESComInterface_t ∗board, float ∗voltage)
- char const ∗ ESCom_GetErrorString (int error, int scope, char ∗buf, int bufLen)

5.5 hal/comboard/hicom.h File Reference

HiCom board type and function declarations.

Data Structures

- struct HiComInterface_t

Macros

- #define **HICOM_NAME** "Dual RS232-HS A"
- #define **HICOM_I2C_SPEED** 100000

Typedefs

- typedef FT_STATUS **HiComStatus_t**
- typedef FT_HANDLE **HiComHandle_t**

Enumerations

- enum **HiComErrorScope_t** { **iesFTDI** = 0x21 }

Functions

- int HiCom_Find (HiComInterface_t ∗board, int ∗count)

  Enumerate HiCom boards Scans USB ports for connected HiCom boards.
- int HiCom_Connect (HiComInterface_t ∗board)

  Connect a HiCom instance Tries to connect to an interface that has been discovered with HiCom_Find() previously.
- int HiCom_Disconnect (HiComInterface_t ∗board)

  Disconnect a HicomBoard.
- int HiCom_SetPower (HiComInterface_t ∗board, bool on)

  Switch sensor power supply on or off.
- int HiCom_I2CWrite (HiComInterface_t ∗board, uint8_t slAddr, uint8_t ∗wData1, int wSize1, uint8_t ∗wData2, int wSize2)
- int HiCom_I2CRead (HiComInterface_t ∗board, uint8_t slAddr, uint8_t ∗wData, int wSize, uint8_t ∗rData, int rSize)
- char const ∗ HiCom_GetErrorString (int error, int scope, char ∗buf, int bufLen)

5.6 hal/hal.h File Reference

Renesas Environmental Sensor HAL definitions.

Data Structures

- struct Interface_t

  A structure of pointers to hardware specific functions. More...

Typedefs

- typedef int(∗ I2CImpl_t) (void ∗, uint8_t, uint8_t ∗, int, uint8_t ∗, int)

  Function pointer type defining signature of I2C functions.
- typedef char const ∗(∗ ErrorStringGenerator_t) (int, int, char ∗, int)

  Function type used for generation of error strings.

Enumerations

- enum GenericError_t { ecSuccess = 0, ecHALError = 0x100 }

  Error code definitions.
- enum ErrorScope_t { esSensor = 0x0000, esAlgorithm = 0x1000, esInterface = 0x2000, esHAL = 0x3000 }

  Success status code and error scopes.
- enum HALError_t {
  heNoInterface = 1, heNotImplemented, heI2CReadMissing, heI2CWriteMissing,
  heSleepMissing, heResetMissing }

  HAL scope error definitions.

Functions

- int HAL_Init (Interface_t ∗hal)

  Initialize hardware and populate Interface_t object.
- int HAL_Deinit (Interface_t ∗hal)

  Cleanup before program exit.
- void HAL_HandleError (int errorCode, void const ∗context)

  Error handling function.
- int HAL_SetError (int error, int scope, ErrorStringGenerator_t errStrFn)

  Function storing error information.
- char const ∗ HAL_GetErrorInfo (int ∗error, int ∗scope, char ∗str, int bufSize)

  Get detailed information for last error.
- char const ∗ HAL_GetErrorString (int error, int scope, char ∗str, int bufSize)

  Error string generator for HAL-scoped errors.

5.7 hal/raspi/rpi.h File Reference

Raspberry PI HAL type and function declarations.

Enumerations

- enum **RPiErrorDefs_t** { **resPiGPIO** = 0x310000, **resI2C** = 0x320000, **recI2CLenMismatch** = 0x320001 }

5.8 hal/zmod4xxx_hal.h File Reference

ZMOD4xxx specific hardware abstraction layer definitions.

Functions

- int zmod4xxx_init (zmod4xxx_dev_t ∗dev, Interface_t ∗hal)

5.9 sensors/hs3xxx.h File Reference

HS3xxx sensor declarations.

Enumerations

- enum HS3xxx_ErrorCodes_t { hteStaleData = 1 }

  Error code definitions specific for the HS3xxx API.

Functions

- int HS3xxx_Init (HSxxxx_t ∗sensor, Interface_t ∗hal)

  Initialize the sensor object.
- int HS3xxx_ReadID (HSxxxx_t ∗sensor, uint32_t ∗id)

  Read the unique sensor ID of the HS3xxx.
- int HS3xxx_Measure (HSxxxx_t ∗sensor, HSxxxx_Results_t ∗results)

  Execute a temperature/humidity measurement cycle.
- int HS3xxx_MeasureStart (HSxxxx_t ∗sensor)

  Start a temperature/humidity measurement cycle.
- int HS3xxx_MeasureRead (HSxxxx_t ∗sensor, HSxxxx_Results_t ∗results)

  Read temperature/humidity results.

5.10 sensors/hs4xxx.h File Reference

HS4xxx sensor declarations.

Enumerations

- enum HS4xxx_ErrorCodes_t { hteHS4xxxCRCError = 1 }

  Error code definitions specific for the HS4xxx API.

Functions

- int HS4xxx_Init (HSxxxx_t ∗sensor, Interface_t ∗hal)

  Initialize the sensor object.
- int HS4xxx_ReadID (HSxxxx_t ∗sensor, uint32_t ∗id)

  Read the unique sensor ID of the HS4xxx.
- int HS4xxx_Measure (HSxxxx_t ∗sensor, HSxxxx_Results_t ∗results)

  Perform a temperature/humidity measurement cycle.
- int HS4xxx_MeasureHold (HSxxxx_t ∗sensor, HSxxxx_Results_t ∗results)

  Perform a temperature/humidity measurement cycle using hold mode.
- int HS4xxx_MeasureStart (HSxxxx_t ∗sensor)

  Start a temperature/humidity measurement cycle in non-hold mode.
- int HS4xxx_MeasureRead (HSxxxx_t ∗sensor, HSxxxx_Results_t ∗results)

  Read temperature/humidity results in non-hold mode.

5.11 sensors/hsxxxx.h File Reference

Renesas humidity sensors (HS3xxx, HS4xxx) abstraction.

Data Structures

- struct HSxxxx_Results_t

  Data structure holding humidity/temperature results. More...
- struct HSxxxx_t

  Data structure holding information required for HSxxxx API operation. More...

Functions

- int HSxxxx_Init (HSxxxx_t ∗sensor, Interface_t ∗hal)

  Initialize the sensor object.
- int HSxxxx_Measure (HSxxxx_t ∗sensor, HSxxxx_Results_t ∗results)

  Perform one temperature measurement.
- char const ∗ HSxxxx_Name (HSxxxx_t ∗sensor)

  Return the temperature/humidity sensor type name.

5.12 sensors/zmod4xxx.h File Reference

zmod4xxx-API functions

Macros

- #define **ZMOD4XXX_ADDR_PID** (0x00)
- #define **ZMOD4XXX_ADDR_CONF** (0x20)
- #define **ZMOD4XXX_ADDR_PROD_DATA** (0x26)
- #define **ZMOD4XXX_ADDR_CMD** (0x93)
- #define **ZMOD4XXX_ADDR_STATUS** (0x94)
- #define **ZMOD4XXX_ADDR_TRACKING** (0x3A)
- #define **ZMOD4XXX_LEN_PID** (2)
- #define **ZMOD4XXX_LEN_CONF** (6)
- #define **ZMOD4XXX_LEN_TRACKING** (6)
- #define **HSP_MAX** (8)
- #define **RSLT_MAX** (32)
- #define STATUS_SEQUENCER_RUNNING_MASK (0x80)
- #define STATUS_SLEEP_TIMER_ENABLED_MASK (0x40)
- #define STATUS_ALARM_MASK (0x20)
- #define STATUS_LAST_SEQ_STEP_MASK (0x1F)
- #define STATUS_POR_EVENT_MASK (0x80)
- #define STATUS_ACCESS_CONFLICT_MASK (0x40)

Functions

- zmod4xxx_err zmod4xxx_calc_factor (zmod4xxx_conf ∗conf, uint8_t ∗hsp, uint8_t ∗config)

  Calculate measurement settings.
- float zmod4xxx_calc_single_rmox (zmod4xxx_dev_t ∗dev, uint8_t ∗adc_result)

  Calculate mox resistance from ADC raw data.
- zmod4xxx_err zmod4xxx_calc_rmox (zmod4xxx_dev_t ∗dev, uint8_t ∗adc_result, float ∗rmox)

  Calculate mox resistance on array of results.
- zmod4xxx_err zmod4xxx_check_error_event (zmod4xxx_dev_t ∗dev)

  Check the error event of the device.
- zmod4xxx_err zmod4xxx_init_measurement (zmod4xxx_dev_t ∗dev)

  Initialize the sensor for corresponding measurement.
- zmod4xxx_err zmod4xxx_init_sensor (zmod4xxx_dev_t ∗dev)

  Initialize the sensor after power on.
- zmod4xxx_err zmod4xxx_null_ptr_check (zmod4xxx_dev_t ∗dev)

  Check if all function pointers are assigned.
- zmod4xxx_err zmod4xxx_prepare_sensor (zmod4xxx_dev_t ∗dev)

  High-level function to prepare sensor.
- zmod4xxx_err zmod4xxx_read_adc_result (zmod4xxx_dev_t ∗dev, uint8_t ∗adc_result)

  Read adc values from the sensor.
- zmod4xxx_err zmod4xxx_read_rmox (zmod4xxx_dev_t ∗dev, uint8_t ∗adc_result, float ∗rmox)

  High-level function to read rmox.
- zmod4xxx_err zmod4xxx_read_sensor_info (zmod4xxx_dev_t ∗dev)

  Read sensor parameter.
- zmod4xxx_err zmod4xxx_read_status (zmod4xxx_dev_t ∗dev, uint8_t ∗status)

  Read the status of the device.
- zmod4xxx_err zmod4xxx_read_tracking_number (zmod4xxx_dev_t ∗dev, uint8_t ∗track_num)

  Read tracking number of sensor.
- zmod4xxx_err zmod4xxx_start_measurement (zmod4xxx_dev_t ∗dev)

  Start the measurement.
- zmod4xxx_err zmod4xxx_start_measurement_at (zmod4xxx_dev_t ∗dev, uint8_t step)

  Start the measurement at an user-defined sequencer step.

5.13 sensors/zmod4xxx_types.h File Reference

zmod4xxx types

Data Structures

- struct zmod4xxx_conf_str

  A single data set for the configuration. More...
- struct zmod4xxx_conf

  Structure to hold the gas sensor module configuration. More...
- struct zmod4xxx_dev_t

  Device structure ZMOD4xxx. More...

Typedefs

- typedef int8_t(∗ zmod4xxx_i2c_ptr_t) (uint8_t addr, uint8_t reg_addr, uint8_t ∗data_buf, uint8_t len)

  function pointer type for i2c access
- typedef void(∗ zmod4xxx_delay_ptr_p) (uint32_t ms)

  function pointer to hardware dependent delay function

Enumerations

- enum zmod4xxx_err {
  ZMOD4XXX_OK = 0, ERROR_INIT_OUT_OF_RANGE, ERROR_GAS_TIMEOUT, ERROR_I2C = -3,
  ERROR_SENSOR_UNSUPPORTED, ERROR_CONFIG_MISSING, ERROR_ACCESS_CONFLICT, ERR↩
  OR_POR_EVENT,
  ERROR_CLEANING, ERROR_NULL_PTR }

  error_codes Error codes