YOSEMITECH

Optical Dissolved Oxygen Sensor

MODBUS RTU Programmer Manuel

Table of Contents

1 MODBUS RTU Overview

1.1 Scope

This document is about MODBUS of optical dissolved oxygen probes with hardware Rev1.0 and software Rev1.5 or later. This document is intended for software programmers with detailed information about MODBUS RTU protocols.

1.2 MODBUS Command Structure

Data format in this document:

----Binary number – shown with suffix B. For example: 10001B

----Decimal number – without nay suffix. For example: 256

----Hexadecimal number—shown with prefix 0x. For example: 0x2A

----ASCII character or string – shown with quotation marks. For example: ” YL0114010022”

1.2.1 Command Structure

MODBUS defines a simple protocol data unit (PDU), which is transparent to communication layer.

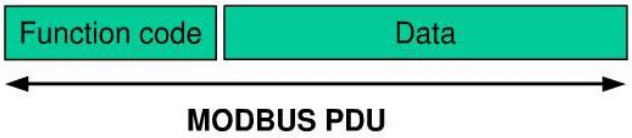

Figure 1: MODBUS Protocol Data Unit

The mapping of MODBUS protocol on a specific bus or network introduces some additional fields on the Protocol Data Unit. The client that initiates a MODBUS transaction builds the MODBUS PDU, and then adds fields in order to build the appropriate communication PDU.

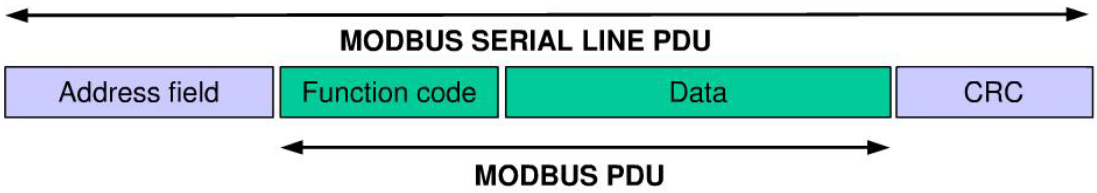

Figure 2: MODBUS Structure for Serial Communication

On a MODBUS serial bus, address field only includes addresses for slave devices.

Note:

- Slave address range for optical dissolved oxygen sensor is: 1…247
- Master device sends a “request frame” with a targeted slave address. When slave device responses, it has to put its own address in the “response frame”, so that master device knows where the response comes from.
- Function code indicates type of operations
- CRC is the result of redundancy check.

1.2.2 MODBUS RTU Transmission Mode

When devices communicate on a MODBUS using RTU (remote terminal unit) mode, each 8-bit byte contains two 4-bit hexadecimal characters. The main advantage of the RTU mode is that it has higher character density, which enables better throughput compare to ASCII mode at same baud rate. Each RTU message must be transmitted in a continuous string of characters.

RTU mode format for each byte (11 bits):

Encoding system 8 bit binary
Each 8-bit packet contains 4-bit hexadecimal characters (0-9, A-F)

Bit per byte: 1 start bit
8 data bits, least significant bit first
No parity check
1 stop bits

Baud rate: 9600bps

Serial transmission of characters:

Every character or byte is sent under this sequence (left to right):

Least Significant Bit (LSB)……Most Significant Bit(MSB)

Start	1	2	3	4	5	6	7	8	Stop

Figure 3: RTU Mode Bit Sequence

CRC Field Structure:

Redundancy check (CRC16)

Frame Structure:

Slave address	Function Code	Data	CRC	
1 byte	1 byte	0…252 bytes	2 bytes	
			CRC Low	CRC High

Figure 4: RTU Message Frame Structure

Maximum size of MODBUS frame is 256 bytes.

1.2.3 MODBUS RTU Message Frame

In RTU mode, message frames need to be separated by an idle interval of at least 3.5 character lengths. In rest of this document, this idle interval is called t3.5.

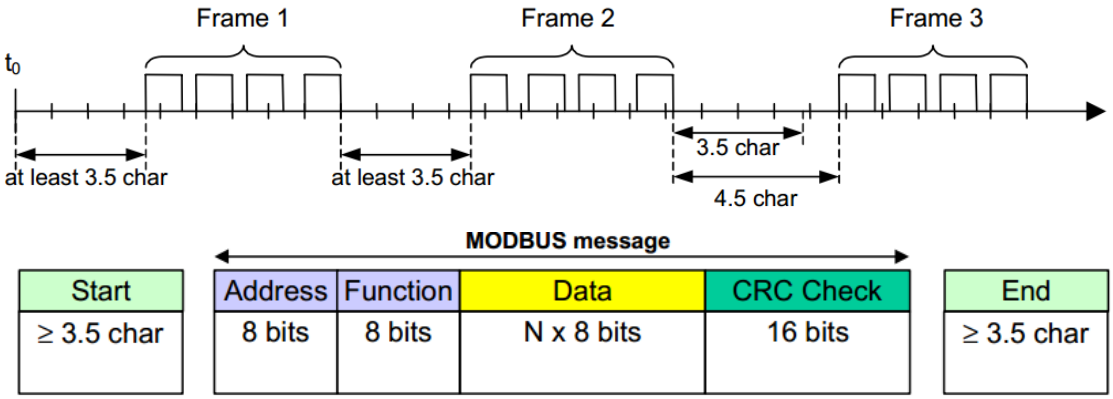

Figure 5: RTU Message Frame

Entire message frame must be sent as continuous stream of characters.

If idle time between two characters is longer than 1.5 characters, the message frame will be considered incomplete, and will be discarded by receiving side.

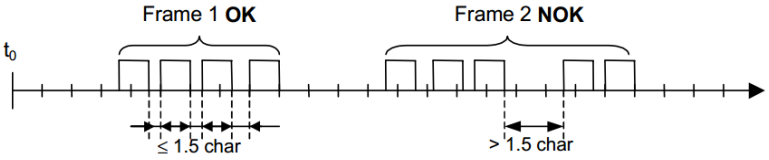

Figure 6: Frame transmission

1.2.4 MODBUS RTU CRC Check

In RTU mode, the error checking field is based on a cyclical redundant checking (CRC) method. The CRC field checks entire content of MODBUS message, regardless of the existence of parity check bit. CRC16 checking method is utilized. CRC result is a 16-bit value with two 8-bit bytes, low order 8-bit byte first followed by high order 8-bit byte.

1.3 MODBUS RTU for YOSEMITECH's Optical Dissolved Oxygen Sensor

Based on standard MODBUS definition, message frame starts with t3.5 idle interval, and similarly, ends with t3.5 idle interval. Device address and Function code are both 8-bit byte. Data character string has n*8 bits, it contains information about register start/end address and number of registers for read/write operation. CRC field is 16 bit in length.

	Start	Device address	Function code	Data	CRC		End
Value	Idle for 3.5 character length	1-247	Comply with MODBUS function code format	Comply with MODBUS data format	CRC Low	CRC High	Idle for 3.5 character length
Length (byte)	3.5	1	1	n	1	1	3.5

Figure 7: Message frame structure for Yosemitech's MODBUS

1.4 MODBUS RTU Function Code for YOSEMITECH's Optical Dissolved Oxygen Sensor

YOSEMITECH's optical dissolved oxygen sensor has two MODBUS function codes:

0x03: Read registers 0x10： Write registers

1.4.1 MODBUS Function Code 0x03: Read Registers

This function code is to read a block of continuous registers from a remote device. Request PDU defines start address and number of registers for the read operation. Register addressing starts from 0. Therefore, addresses for register 1-16 are 0-15. Data for each register in Response message have two bytes. For each register data, first byte is for high bits, and second byte for low bits.

Request Frame:

Function code	1 Byte	0x03
Start address	2 Bytes	0x0000….0xfffff
Number of registers	2 Bytes	1…125

Figure 8: Request frame for read registers

Response Frame:

Function code	1 byte	0x03
Number of byte	1 byte	N×2
Register data	N×2 bytes	

N = number of registers

Figure 9: Response frame for read registers

Below is an example of Request and Response frames (Read register 108-110. Register 108 is read only with 2-byte value of 0X022B. Registers 109-110 have values of 0X0000 and 0X0064).

Request Frame		Response Frame	
Data format	Hexadecimal	Data Format	Hexadecimal
Function code	0x03	Function code	0x03
Start address(high bits)	0x00	Number of bytes	0x06
Start address (low bits)	0x6B	Register value (high bits, 108)	0x02
Number of registers (high bits)	0x00	Register value (low bits, 108)	0x2B
Number of registers (low bits)	0x03	Register value (high bits, 109)	0x00
		Register value (low bits, 109)	0x00
		Register value (high bits, 110)	0x00
		Register value (low bits, 110)	0x64

Figure 10: Example of request and response frame for read operation

1.4.2 MODBUS Function Code 0x10: Write Registers

This function code is to write a block of continuous registers at a remote device. Request frame contains register data. Each register data have two character bytes. Response frame contains function code, start address, and number of registers that completed write operation.

Request Frame:

Function code	1 byte	0x10
Start address	2 bytes	0x0000….0xffff
Number of registers	2 bytes	0x0001….0x0078
Number of bytes	1 byte	N×2
Register data	N×2 bytes	value

N = number of registers

Figure 11: Request frame for write operation

Response Frame

Function Code	1 byte	0x10
Start address	2 bytes	0x0000….0xffff
Number of registers	2 bytes	1…123(0x7B)

Figure 12: Response frame for write operation

Below is an example of Request frame and Response frame (write 0x000A and 0x0102 to two registers starting from address 2):

Request Frame		Response Frame	
Data Format	Hexadecimal	Data Format	Hexadecimal
Function code	0x10	Function code	0x10
Start address (high bits)	0x00	Start address (high bits)	0x00
Start address (low bits)	0x01	Start address (low bits)	0x01
Number of registers (high bits)	0x00	Number of registers (high bits)	0x00
Number of registers (low bits)	0x02	Number of registers (low bits)	0x02
Number of bytes	0x04		
Register value (high bits)	0x00		
Register value (low bits)	0x0A		
Register value (high bits)	0x01		
Register value (low bits)	0x02		

Figure 13: Example of Request frame and response frame for write operation

1.5 Data formats in optical dissolved oxygen sensor

1.5.1 Floating-point number

Definition: floating point number, comply with IEEE754 (single precision)

Note	Sign	Exponent	Fraction	Total
bit	31	30…23	22…0	32
Exponent deviation	127			

Figure 14: Single floating point number definition (4 bytes, 2 MODBIS registers)

Example: Convert decimal number 17.625 to binary number

Step 1: Convert decimal number 17.625 to a floating point number with binary format

First, convert integer to binary

$17_{decimal} = 16 + 1 = 1\times2^4 + 0\times2^3 + 0\times2^2 + 0\times2^1 + 1\times2^0$

Thus, integer 17 in binary format is 10001B

Then convert decimal part to binary

$0.625_{decimal} = 0.5 + 0.125 = 1\times2^{-1} + 0\times2^{-2} + 1\times2^{-3}$

Thus, 0.625 in binary format is 0.101B

Combine above together, 17.625 in binary format is 10001.010B

Step 2: Calculate exponent

Left shift the binary number 10001.010B until only bit left before the decimal point --- 10001.101B = 1.0001101 B$\times 2^4$, so exponent value is 4. By adding 127, we have 131, which is 10000011B in binary format

Step 3: Get fraction

Fraction is simply the number after decimal point. Thus from 1.0001101B, fraction number is 0001101B. IMPORTANT NOTE about the 23 bit fraction number: the first bit which on the left side of decimal point is hidden bit and does not need to be compiled.

Step 4: Sign definition

Sign bit is 0 if the number is positive. Sign is 1 if the number is negative. For 17.625, sign

bit is 0.

Step 5: Convert to floating point number

1 Sign bit + 8-bit exponent + 23-bit fraction

0 10000011 00011010000000000000000B

(Corresponding hexadecimal number is 0x418D0000)

Sample code:

1. If your compiler has similar library functions, it can be called directly. For example if C language is used, we can directly call memcpy() function in C library to convert floating point number. Sample code:

```
float    floatdata;//floating point data to be converted
void*    outdata;
memcpy(outdata,&floatdata,4);
```

If floatdata=17.625,

In little-endian storage mode after the function is called:

Value at address of outdata is 0x00

Value at address of (outdata+1) is 0x00

Value at address of (outdata+2) is 0x8D

Value at address of (outdata+3) is 0x41

In big-endian storage mode after the function is called:

Value at address of outdata is 0x41

Value at address of (outdata+1) is 0x8D

Value at address of (outdata+2) is 0x00

Value at address of (outdata+3) is 0x00

2. If your complier doesn't have the conversion function, then the following function can be used:

```
void memcpy(void *dest,void *src,int n)
{
    char *pd = (char *)dest;
    char *ps = (char *)src;
    for(int i=0;i<n;i++)    *pd++ = *ps++;
}
```

Then you can get same result by calling this function memcpy(outdata,&floatdata,4);

Example: Convert binary floating point number 0100 0010 0111 1011 0110 0110 0110 0110B to a decimal number

Step 1: Separate this binary number 0100 0010 0111 1011 0110 0110 0110 0110B and get values of Sign , exponent and fraction.

0 10000100 11110110110011001100110B

1 Sign bit 8-bit exponent 23-bit fraction

Sign bit(s): 0

Exponent(E):10000100B=$1\times2^7+0\times2^6+0\times2^5+0\times2^4+0\times2^3+1\times2^2+0\times2^1+0\times2^0$

=128+0+0+0+0+4+0+0=132

Fraction(M)：11110110110011001100110B =8087142

Step 2: Calculate decimal value

$D = (-1)^S \times (1.0+M/2^{23}) \times 2^{E-127}$

$= (-1)^0 \times (1.0+8087142/2^{23}) \times 2^{132-127}$

$= 1 \times 1.964062452316284 \times 32$

$= 62.85$

Reference code:

```
float floatTOdecimal(long int byte0, long int byte1, long int byte2, long int byte3)
{
        long int realbyte0,realbyte1,realbyte2,realbyte3;
        char S;
        long int      E,M;
        float D;
        realbyte0 = byte3;
        realbyte1 = byte2;
        realbyte2 = byte1;
        realbyte3 = byte0;

        if((realbyte0&0x80)==0)
        {
            S = 0; //Positive
         }
         else
        {
            S = 1; //Negative
        }
        E = ((realbyte0<<1)|(realbyte1&0x80)>>7)-127;
        M = ((realbyte1&0x7f) << 16) | (realbyte2<< 8)| realbyte3;
        D = pow(-1,S)*(1.0 + M/pow(2,23))* pow(2,E);
        return D;
}
```

Note:

- Function parameters byte0, byte1, byte2 and byte3 represent the 4 sections of a binary floating number.
- Return value is value of decimal number after conversion

For example when a command is sent to a sensor to get temperature value, response frame from the sensor will have measured temperature. If the values are 4 byte floating point number 0x00,0x00,0x8d,0x41, then the following function can be used to get temperature in decimal value:

float temperature = floatTOdecimal(0x00, 0x00, 0x8d, 0x41);

and temperature = 17.625.

1.5.2 Characters

Definition: Character is shown by ASCII code.

Example: String “YL” could be shown by corresponding ASCII codes (refer to ASCII character chart)

“Y” is 0x59

“L” is 0x4C

2 MODBUS RTU Commands for Optical Dissolved Oxygen Sensor

2.1 Overview

In order to communicate with optical dissolved oxygen via MODBUS RTU, master terminal software will be needed. MODBUS RTU is an open standard. There are free commercial software tools available. For applications described in this document, MODBUS register address starts from 1. However, slave address in MODBUS protocol starts from 0, and usually master software compiles addresses. For example, register address 2090 will be compiled by master software as address 2089.

2.2 Command Description

2.2.1 Set Slave Device ID

Purpose: Set MODBUS slave address to a sensor probe. Range of address is 1~247.

Sensor probe slave address can be set via MODBUS register 0x3000:

Start address	Number of registers	Register 1	MODBUS Function code
0x3000	0x01	New Slave address	0x10

Figure 15: Set slave ID command

Below is an example of request and response frames for setting slave device ID command. Old slave address is 0x01, new address is 0x14.

Definition	Address	Function code	Start address		Number of registers		Number of byte	Register value		CRC	
Byte	0	1	2	3	4	5	6	7	8	9	10
Value	0x01	0x10	0x30	0x00	0x00	0x01	0x02	0x14	0x00	0x99	0x53

Figure 16: Example of Request frame to set slave ID *Note: byte 8 is reserved

Definition	Address	Function code	Start address		Number of registers		CRC	
Byte	0	1	2	3	4	5	6	7
Value	0x01	0x10	0x30	0x00	0x00	0x01	0x0E	0xC9

Figure 17: Example of response frame for Set slave ID command

2.2.2 Get SN

Purpose: Get sensor probe's serial number (SN). Each sensor probe has a unique SN.

Serial Number can be read from 7 continuous MODBUS registers starting from address 0x0900

Start Address	Number of registers	Register 1-7	MODBUS Function code
0x0900	0x07	SN	0x03

Figure 18: Register definition for Get SN command

Below is an example of request and response frames to get SN "YL0114010022" from a slave device (address 0x01)

Definition	Address	Function code	Starting address		Number of registers		CRC	
Byte	0	1	2	3	4	5	6	7
Value	0x01	0x03	0x09	0x00	0x00	0x07	0x07	0x94

Figure 19: Request frame to get SN

Definition	Address	Function code	Number of byte	Register value			CRC	
Byte	0	1	2	3	4-15	16	17	18
Value	0x01	0x03	0x0E	0x00	"YL0114010022"	0x00	0x19	0x66

Figure 20: Response frame sample for Get SN command

Note: SN value is in ASCII code as below:

Byte	4	5	6	7	8	9	10	11	12	13	14	15
Value	0x59	0x4C	0x30	0x31	0x31	0x34	0x30	0x31	0x30	0x30	0x32	0x32

Figure 21: Sensor probe's SN

2.2.3 Start Measurement

Purpose：Set probe in continuous light emitting mode and start measuring dissolved oxygen.

MODBUS register 0x2500 is used. The Probe starts in continuous light emitting mode by default.

Starting address	Number of registers	MODBUS Function code
0x2500	0x01	0x03

Figure 22: Start measurement command definition

Below is an example of request and response frames for sending a Start Measurement command to a device with slave address 0x01.

Definition	Device address	Function code	Start address		Number of registers		CRC	
Byte	0	1	2	3	4	5	6	7
Value	0x01	0x03	0x25	0x00	0x00	0x01	0x8F	0x06

Figure 23: Request frame of a start measurement comment

Definition	Device address	Function code	Number of bytes	Register value	CRC	
Byte	0	1	2	3~4	5	6
Value	0x01	0x03	0x00	meaningless		

Figure 24: Response frame of a start measurement command

2.2.4 Get Temperature and DO values

Purpose：Get temperature and DO measurement results. Temperature unit is Celsius degree (°C), DO unit is percentage (%). User calibration process is automatically applied to DO value.

Temperature and DO data can be read from 4 continuous MODBUS registers starting from address 0x2600.

Start address	Number of registers	Register 1-2	Register 3-4	MODBUS function code
0x2600	0x04	Temperature	DO value	0x03

Figure 25: Register definition for Get temperature and DO command

Below is an example of request and response frames for getting temperature and DO command, assuming slave device address is 0x01, returned temperature is 17.625°C and DO value is 17.625.

Definition	Device address	Function code	Start address		Number of registers		CRC	
Byte	0	1	2	3	4	5	6	7
Value	0x01	0x03	0x26	0x00	0x00	0x04	0x4F	0x41

Figure 26: Request frame for Get Temperature and DO command

Definition	Device address	Function code	Number of bytes	Register value		CRC	
Byte	0	1	2	3-6	7-10	11	12
Value	0x01	0x03	0x08	17.625	17.625	0x12	0x65

Figure 27: Response frame for Get Temperature and DO command

Note: Temperature and DO values are floating point number in little-endian storage mode. See sample below:

Temperature（3-6）				DO value（7-10）			
0x00	0x00	0x8D	0x41	0x00	0x00	0x8D	0x41

Figure 28: Registers for temperature and DO values.

2.2.5 Get Software and Hardware Rev

Purpose: Get current hardware and software Release Version.

Hardware and software release version numbers of a sensor probe can be read from 2 continuous registers starting from address 0x0700.

Start address	Number registers	Register 1	Register 2	MODBUS function code
0x0700	0x02	HW Rev	SW Rev	0x03

Figure 29: Register definitions for Get software and hardware Rev command

Below is an example of request and response frames for getting hardware and software release version, assuming device slave address is 0x01, returned value for hardware Rev is 2.0 and software Rev is 5.7.

Definition	Device address	Function code	Start address		Number of registers		CRC	
Byte	0	1	2	3	4	5	6	7
Value	0x01	0x03	0x07	0x00	0x00	0x02	0xc5	0x7f

Figure 30: Request frame of Get Hardware and Software Rev command

Definition	Device address	Function code	Number of bytes	Register value				CRC	
Byte	0	1	2	3-4		5-6		7	8
Value	0x01	0x03	0x04	0x02	0x00	0x05	0x07	0xb9	0x19

Figure 31: Response frame of Get Hardware and Software Rev Command

2.2.6 Stop Measurement

Purpose：After stable test result is obtained, stop measurement activities. If measurement need to start again , use command **Start Measurement.**

MODBUS register 0x2E00 is used for this command.

Start address	Number of registers	MODBUS function code
0x2E00	0x01	0x03

Figure 32: Register definition for Stop measurement command

Below is an example of request and response frames for a device with slave address 0x01 to stop measurement activities.

Definition	Device address	Function code	Start address		Number of registers		CRC	
Byte	0	1	2	3	4	5	6	7
Value	0x01	0x03	0x2E	0x00	0x00	0x01	0x8D	0x22

Figure 33: Request frame of stop measurement command

Definition	Device address	Function code	Number of bytes	Register value	CRC	
Byte	0	1	2	3~4	5	6
Value	0x01	0x03	0x00	meaningless		

Figure 34: Response frame of stop measurement command

2.2.7 Get User Calibration Coefficients

Purpose: Get two calibration coefficients K and B. (This is to eliminate measurement errors caused by aging or other reasons. User calibration equation is: DO_{final}=K*DO +B; default values are: K=1; B=0)

User calibration coefficients (K and B) can be read from 4 continuous MODBUS registers starting from address 0x1100.

Start address	Number of registers	Register 1-2	Register 3-4	MODBUS function code
0x1100	0x04	K value	B value	0x03

Figure 35: Register definition for Get User calibration coefficients command

Below is an example of request and response frames for getting customer calibration coefficients from a device with slave address 0x01, assuming returned values are: K=1.0; B=0.0.

Definition	Device address	Function code	Start address		Number of registers		CRC	
Byte	0	1	2	3	4	5	6	7
Value	0x01	0x03	0x11	0x00	0x00	0x04	0x41	0x35

Figure 36: Request frame of Get customer calibration coefficient command

Definition	Device address	Function code	Number of bytes	Register value		CRC	
Byte	0	1	2	3-6	7-10	11	12
Value	0x01	0x03	0x08	1.0	0.0	0x9E	0x12

Figure 37: Response frame of get customer calibration coefficient command

Note: K and B are floating point numbers in little-endian storage mode

K(3-6)				B(7-10)			
0x00	0x00	0x80	0x3F	0x00	0x00	0x00	0x00

Figure 38: Registers for two coefficients K and B.

2.2.8 Set Customer Calibration Coefficients

Purpose: Set two calibration coefficients K and B.

Customer coefficients (K and B) can be set at 4 continuous MODBUS registers starting from address 0x1100.

Start address	Number of registers	Register 1-2	Register 3-4	MODBUS function code
0x1100	0x04	K	B	0x10

Figure 39: Register definition for set customer calibration command

Below is an example of request and response frames for setting customer calibration coefficients, Assuming slave address is 0x01, coefficients are K=1.0; and B=0.0.

Definition	Device address	Function code	Start address		Number of registers		Number of bytes	Register value		CRC	
Byte	0	1	2	3	4	5	6	7-10	11-14	15	16
Value	0x01	0x10	0x11	0x00	0x00	0x04	0x08	1.0	0.0	0x81	0xAE

Figure 40: Request frame of set customer calibration coefficient command

Note: Coefficients K and B, floating point numbers in little-endian storage mode

K(7-10)				B(11-14)			
0x00	0x00	0x80	0x3F	0x00	0x00	0x00	0x00

Figure 41: Registers for two coefficients K and B

Definition	Device address	Function code	Start address		Number of registers		CRC	
Byte	0	1	2	3	4	5	6	7
Value	0x01	0x10	0x11	0x00	0x00	0x04	0Xc4	0xf6

Figure 42: Response frame of set customer calibration coefficient command

2.2.9 Set Optical Sensor Cap Coefficients

Purpose：Set sensor cap coefficients (K0~K7), this is necessary step to replace sensor caps.

Sensor cap coefficients can be set at 16 continuous MODBUS registers starting from address 0x2700.

Start address	Number of registers	Register 1-16	MODBUS function code
0x2700	0x10	K0- K7	0x10

Figure 43: Request frame of set sensor cap coefficient command

Below is an example of request and response frames for setting sensor cap coefficients to a device with slave address 0x01.

Definition	Device address	Function code	Start address		Number of registers		Number of bytes	Register value	CRC	
Byte	0	1	2	3	4	5	6	7-38	39	40
Value	0x01	0x10	0x27	0x00	0x00	0x10	0x20	K0-K7	XX	XX

Figure 44: Request frame of set sensor cap coefficient command

Note: Ki(i=0-7) sensor cap coefficients, floating point number in little-endian storage mode

Definition	Device address	Function code	Start address		Number of registers		CRC	
Byte	0	1	2	3	4	5	6	7
Value	0x01	0x10	0x27	0x00	0x00	0x10	0xcb	0x71

Figure 45: Response frame of set sensor cap coefficient command

2.2.10 Get Slave Device ID

Purpose: Get current MODBUS slave address to a sensor probe. Use 0xFF as fixed Device address. Sensor probe slave address can be read from MODBUS registers 0x3000.

Start address	Number of registers	Register 1	MODBUS Function code
0x3000	0x01	Current Slave address	0x10

Figure 46: Get slave ID command

Below is an example of request and response frames for getting slave device id, assuming returned address is 0x03.

Definition	Device address	Function code	Start address		Number of registers		CRC	
Byte	0	1	2	3	4	5	6	7
Value	**0xFF**	0x03	0x30	0x00	0x00	0x01	0x9E	0xD4

Figure 47: Request frame of get slave device ID comment

Definition	Device address	Function code	Number of bytes	Register value		CRC	
Byte	0	1	2	3	4	5	6
Value	0xFF	0x03	0x02	0x03	0x00(reserve)	0x91	0x60

Figure 48: Response frame of get slave device ID comment

3 Procedure to get DO value

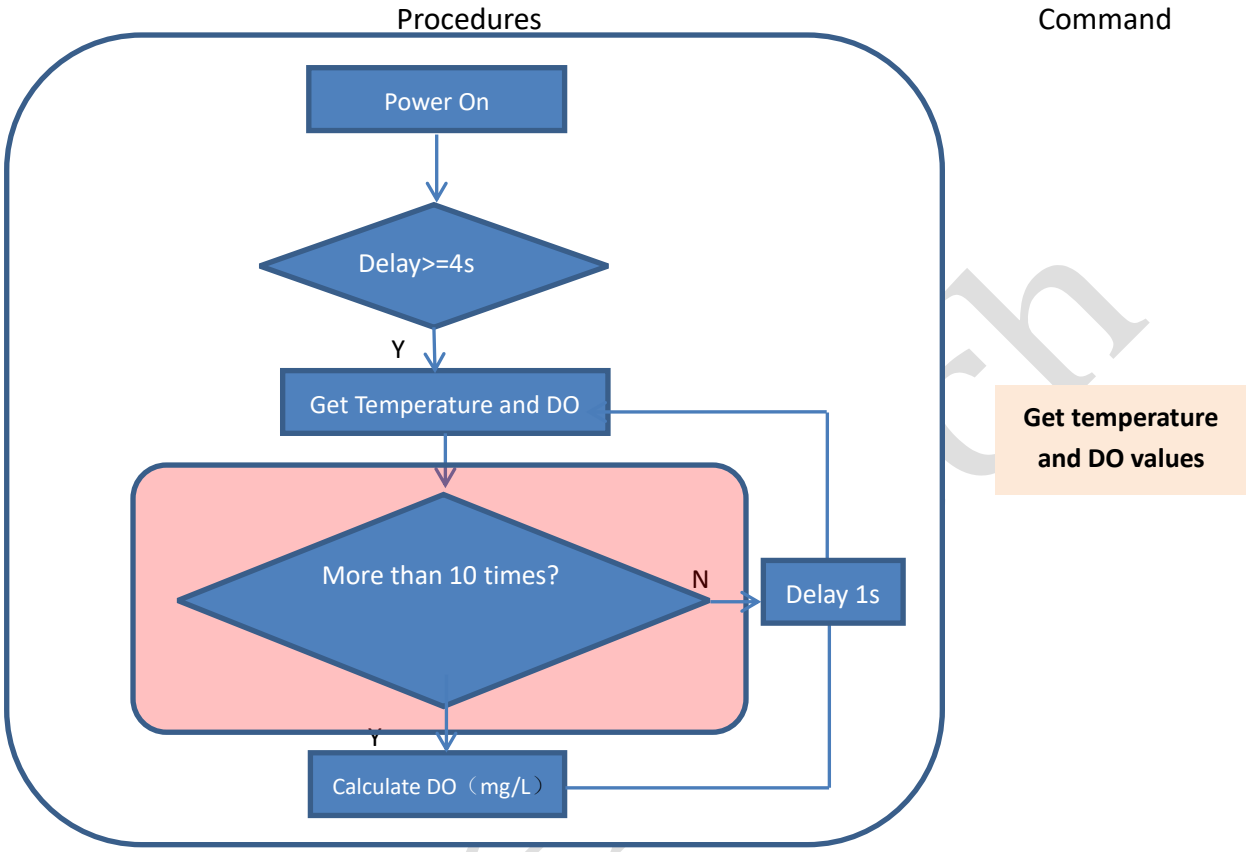

Figure 46：Flow chart to get DO measurement

- **Start Measurement – sensor probe start emitting LED light, and perform DO measurement with automatic calibration and compensation.**
- **Get temperature and DO values – Get measurement results including temperature (°C) and DO (%) after 1 second of measurements.**

  Note: Please pay attention to highlighted portion (red) in the flow chart above. It's highly recommended that customers get an average DO results (%) after 10 consecutive measurements, then convert the average DO percentage to a DO value in mg/L unit.
- **Calculate DO（mg/L）, converting the average DO percentage to a DO value in mg/L unit.**

  According to the formula: DO(mg/L)=DO(%)*X1*X2*1.4276;

  1 ml/L = 1.4276 mg/L;

  lnX1= Al + A2 100/T + A3 ln T/100 + A4 T/100 + S* [B1 + B2 T/100 + B3 (T/100)^2];

  Al = -173.4292, B1 = - 0.033096,

  A2 = 249.6339, B2 = 0.014259,

  A3 = 143.3483, B3 = - 0.001700;

  A4 = -21.8492;

  T =273.15 + t ,T represent for Kelvin temperature and t represent for Celsius temperature;

S is salinity, S=0 in pure water;

X2= (Phmg - u) / (760 - u);

Phmg= pressure * 760 / 101.325, pressure is the barometer in kPa unit;

Logu= 8.10765 - (1750.286/ (235+t)), t represent for Celsius temperature.

Reference code:

```
#include <math.h>

float pressure = 0.0;
float Phmg= 0.0;
float t = 0.0;
float T = 0.0;
float S = 0.0;

T = 273.15 + t; //t is current temperature which get from probe
X1' = -173.4292                          // X1' = ln X1
      + 249.6339*(100/ T)
      + 143.3483*log(T /100)       //Function log() is equal to ln(x)
      + -21.8492*( T /100)
      +S*(-0.033096 + (0.014259* T)/100
      -0.001700*( T /100)*( T /100));
X1 = exp(X1');

// log u = 8.10765 - (1750.286/ (235+t))
u' = 8.10765 - (1750.286/ (235 + t));// u' = log u
u = pow(10, u');                                          //u=10^u'

Phmg = pressure*760/101.325;
X2   =   ((Phmg - u)/(760 - u));
DO(mg/L)= DO(%)*X1*X2*1.4276;
```