Smart Clothing Sensor Hub S/W Specification V0.9

AiQ Smart Clothing Ltd.

Revisioin History

Revision	Date	Author	Changes
0.1	2016/9/28	John Chen	Preliminary release
0.2	2016/10/06	John Chen	1. Updated 4.1.3, 4.2.1, 4.2.2 CMD table and 4.3 power management 2. Added 4.4 state machine chart
0.3	2016/10/07	John Chen	1. Updated 2. H/W block diagram 2. Added 5. S/W implementation guideline of application processor
0.4	2016/10/10	John Chen	1. Updated 4.1.3 sensor data fusion 2. Updated 4.3 power management 3. Updated 4.4 state machine 4. Added chapter 5 & 6
0.5	2016/10/20	John Chen	1. Corrected typo in 4.1.3 title 2. Updated 4.1.3 RTC interval to 1ms 3. Update 4.1.1 for the initial settings of accelerometer & gyroscope sensors
0.6	2016/10/21	John Chen	1. Added H/W block diagram
0.7	2016/11/21	John Chen	1. Added 8 Kbit EEPROM into figure 1 “H/W block diagram” 2. Updated figures in 5.2 State machine.
0.8	2016/11/24	John Chen	Updated “H/W block diagram”.
0.9	2016/12/19	John Chen	Corrected some wordings.

Table of content

1. Overview

This document defines the SW architecture & implementation guidelines for AiQ smart clothing sensor hub.

2. H/W block diagram

Two key GPIOs are used on application processor and sensor hub for following purposes.

1. Cloth attached detection pin
   - The pin is an input pin to sensor hub.
   - The pin is pulled high by default and cloth will pull it low while cloth is attached.
   - The pin will be pulled high again after cloth is de-attached.

2. Sensor hub wakeup pin
   - The pin is an output pin to application processor and an input pin to sensor hub.
   - The pin should be pulled high by default and application procesor pulls it low while it wants to wakeup sensor hub.
   - The pin should be low all the time while sensor hub is in active mode.
   - Application processor pull high the pin while it wants sensor to enter stop mode.

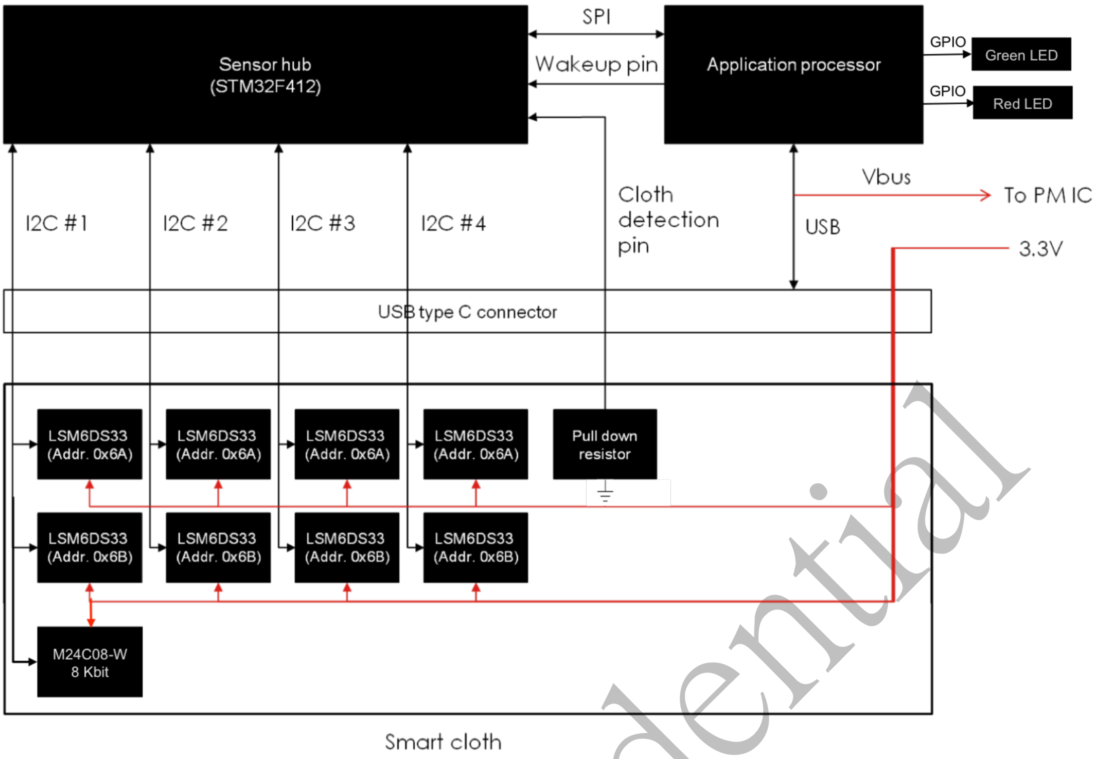

Figure 1: H/W block diagram

A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12
GND	SDA1	SDA2	V_{BUS}	CC1	D+	D-	ID	V_{BUS}	SDA3	SDA4	GND
GND	SCL1	SCL2	V_{BUS}	3V3	D-	D+	CC2	V_{BUS}	SCL3	SCL4	GND
B12	B11	B10	B9	B8	B7	B6	B5	B4	B3	B2	B1

Figure 2: Type C connector pin definition (sensor hub side)

A12	A11	A10	A9	A8	A7	A6	A5	A4	A3	A2	A1
GND	SDA4	SDA3	V_{BUS}	ID	D-	D+	CC1	V_{BUS}	SDA2	SDA1	GND
GND	SCL4	SCL3	V_{BUS}	CC2	D+	D-	3V3	V_{BUS}	SCL2	SCL1	GND
B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12

Figure 3: Type C connector pin definition (smart cloth side)

3. S/W block diagram

To be added.

4. S/W implementation guidelines of sensor hub

In this chapter, following items are defined.

1. Sensor fusion
2. Data transfer
   - Sending sensor fusion data to application processor
   - Communication protocol
3. Power management
4. State machine

4.1 Sensor fusion

The motion sensor data is read at the rate of 200Hz, meaning at 5ms interval, and be sent to application processor for motion capture. Considering the sensors are connected to sensor hub by I2C, sensor hub needs to have ability to read at least 8 sensors (may be 6-axis or 9-axis sensors) at the required interval.

To meet the timing requirement, sensor hub is designed as follows.

1. Multiple I2C buses are used to read sensor data to minimize reading time
2. Hardware I2C is used instead of software ones
3. Two sensors w/ different I2C address are connected to a single I2C bus

4.1.1 Sensor initialization

All the sensors need to be properly initialized after connected to sensor hub.

1. Accelerometer: +/- 8G
2. Gyroscope: +/- 2000 dps

4.1.2 Sensor data capturing

Sensor hub starts sensor data capturing as long as it receives "START" command from application processor and stop capturing while receiving

"STOP" command. After capturing the sensor data, the raw data will be further processed which called sensor fusion. Two buffers are used for storing the senor data captured and fused as follows.

1. Buffer for sensor raw data

   This is the buffer used for storing sensor raw data during sensor data capturing process and will be cleared while next capture starts.

2. Buffer for sensor fusion data
   - After sensor data captured, the raw data will be further processed into the format for application processor. This buffer contains the fused data for application processor to read.
   - The buffer needs to have capability for storing several sensor fusion data if motion algorithm supports aggregated report data i.e. several sensor fusion data will be aggregated together and application processor will read it at once.

4.1.3 Sensor data fusion

The fused sensor data needs to contain data in following table. The data format applies to both single and multiple aggregated sensor data.

Item	Description	Length	Data
Timestamp	Timestamp of the read sensor data.	4 bytes	The RTC timer count. RTC timer interval: 1ms
I2C bus ID	This field carries the I2C bus ID as well as the amount of motion sensors connected.	1 byte	1. #5~8 bits represents the I2C bus ID e.g. 1st I2C, 2nd I2C, 3rd I2C, 4th I2C and etc. 2. #1~4 bits represents how many sensor connected to the I2C bus. For example:

			0x12: 1st I2C bus connects 2 motion sensors
Sensor type	The type of sensor e.g. 6-axis or 9-axis motion sensor	1 byte	1: 6-axis sensor 2: 9-axis sensor Others: reserved
6-axis motion sensor raw data	Raw data of a 6-axis motion sensor	12 bytes	Accel. X + Accel. Y + Accel. Z + Gyro X + Gyro Y + Gyro Z
9-axis motion sensor raw data	Raw data of a 9-axis motion sensor	18 bytes	Accel. X + Accel. Y + Accel. Z + Gyro X + Gyro Y + Gyro Z + Magnet X + Magnet Y + Magnet Z

Table 1: Senor fusion data report format

Given four 6-axis and four 9-axis motion sensors are connected to four I2C buses of the sensor hub, then the sensor fusion data format will be as follows, 137 bytes in total.

I2C bus ID (0xFF)	Timestamp byte 1 (LSB)	Timestamp byte 2	Timestamp byte 3	Timestamp byte 4 (MSB)	I2C bus ID (0x12)	Sensor type (1)	Accel. X LSB
Accel. X MSB	Accel. Y LSB	Accel. Y MSB	Accel. Z LSB	Accel. Z MSB	Gyro X LSB	Gyro X MSB	Gyro Y LSB
Gyro Y MSB	Gyro Z LSB	Gyro Z MSB	Sensor type (2)	Accel. X LSB	Accel. X MSB	Accel. Y LSB	Accel. Y MSB
Accel. Z LSB	Accel. Z MSB	Gyro X LSB	Gyro X MSB	Gyro Y LSB	Gyro Y MSB	Gyro Z LSB	Gyro Z MSB
Magnet. X LSB	Magnet. X MSB	Magnet. Y LSB	Magnet. Y LSB	Magnet. Z LSB	Magnet. Z LSB	I2C bus ID (0x22)	Sensor type (1)
Accel. X LSB	Accel. X MSB	Accel. Y LSB	Accel. Y MSB	Accel. Z LSB	Accel. Z MSB	Gyro X LSB	Gyro X MSB

Gyro Y LSB	Gyro Y MSB	Gyro Z LSB	Gyro Z MSB	Sensor type (2)	Accel. X LSB	Accel. X MSB	Accel. Y LSB
Accel. Y MSB	Accel. Z LSB	Accel. Z MSB	Gyro X LSB	Gyro X MSB	Gyro Y LSB	Gyro Y MSB	Gyro Z LSB
Gyro Z MSB	Magnet. X LSB	Magnet. X MSB	Magnet. Y LSB	Magnet. Y LSB	Magnet. Z LSB	Magnet. Z LSB	I2C bus ID (0x32)
Sensor type (1)	Accel. X LSB	Accel. X MSB	Accel. Y LSB	Accel. Y MSB	Accel. Z LSB	Accel. Z MSB	Gyro X LSB
Gyro X MSB	Gyro Y LSB	Gyro Y MSB	Gyro Z LSB	Gyro Z MSB	Sensor type (2)	Accel. X LSB	Accel. X MSB
Accel. Y LSB	Accel. Y MSB	Accel. Z LSB	Accel. Z MSB	Gyro X LSB	Gyro X MSB	Gyro Y LSB	Gyro Y MSB
Gyro Z LSB	Gyro Z MSB	Magnet. X LSB	Magnet. X MSB	Magnet. Y LSB	Magnet. Y LSB	Magnet. Z LSB	Magnet. Z LSB
I2C bus ID (0x42)	Sensor type (1)	Accel. X LSB	Accel. X MSB	Accel. Y LSB	Accel. Y MSB	Accel. Z LSB	Accel. Z MSB
Gyro X LSB	Gyro X MSB	Gyro Y LSB	Gyro Y MSB	Gyro Z LSB	Gyro Z MSB	Sensor type (2)	Accel. X LSB
Accel. X MSB	Accel. Y LSB	Accel. Y MSB	Accel. Z LSB	Accel. Z MSB	Gyro X LSB	Gyro X MSB	Gyro Y LSB
Gyro Y MSB	Gyro Z LSB	Gyro Z MSB	Magnet. X LSB	Magnet. X MSB	Magnet. Y LSB	Magnet. Y LSB	Magnet. Z LSB
Magnet. Z LSB							

Figure 4: Example senor fusion data report format

4.2 Data transfer

Sensor hub connects to application processor by SPI interface and this chapter will talk about how the data transfer works as well as the communication protocol.

4.2.1 Sending sensor fusion data to application processor

Sensor hub captures the sensor data at a pre-configured interval (default is 5ms, meaning 200Hz), and will notify application processor to read the fusion data at a pre-configured interval (default is the same as sampling interval). Sensor hub needs to make sure the sensor fusion data will not be corrupted while application processor is reading it i.e. the buffer should not be updated with new data unless application processor is not reading it.

After notified by sensor hub, application processor should issue a READ command and sensor hub will reply with the data defined in 4.1.3.

4.2.2 Communication protocol

The protocol is used for communication between application processor and sensor hub. Please note every command is followed by a response from sensor hub.

The protocol packet format is as following.

CMD ID (1 byte)	Length (1 byte)	Data (Length is specified in length field)

Figure 5: Communication protocol packet format

The CMD ID is defined in following table.

CMD ID	Description	Length	Data
0x01	Get/Set cloth info including sensor #, type & I2C slave address on each I2C bus	AP->Hub: TBD Hub->AP: TBD	AP->Hub: TBD Hub->AP: TBD
0x02	Get sensor fusion	AP->Hub: 1 byte	AP->hub: Reserved

	data length	Hub->AP: 1 byte	Hub->AP: Sensor fusion data length
0x03	Get/Set # of sensor fusion data to be reported at once (Default is 1, meaning data is reported at every sampling interval)	AP->Hub: 1 byte Hub-> AP: 1 byte	AP->hub: - 0x00: Get # of reported data from sensor hub - Otherwise the new requested # e.g. 0x2 means 2 sensor fusion data is reported at once. Hub->AP: CMD result - 0x00: Requested # of report data is not supported - Otherwise: Return current/new # of report data
0x04	Sensor calibration operation	AP->Hub: 1 byte Hub->AP: 1 byte	AP->hub: Operation instruction - 0x00: Stop calibration - 0x01: Start calibration - 0x02: Get calibration status Hub->AP: CMD result - 0x00: Failure - 0x01: Success - 0x02: Calibration is ongoing
0x05	Get/Set sampling rate (Default sampling rate is 200Hz)	AP->Hub: 1 byte Hub->AP: 1 byte	AP->hub: - 0x00: Get current sampling rate from sensor hub - Otherwise the new requested sampling rate e.g. 0x64 means 100 Hz and 0xC8 means 200Hz. Hub->AP: CMD result - 0x00: Requested sampling rate is not supported - Otherwise: Return

			current/new sampling rate
0x10	Start/stop sensor fusion	AP->Hub: 1 byte Hub->AP: 1 byte	AP->Hub: Start/stop instruction - 0x00: Stop - 0x01: Start Hub->AP: CMD result - 0x00: Failure - 0x01: Success
0x11	Read sensor fusion data	AP->Hub: 1 byte Hub->AP: sensor fusion data length	AP->Hub: Reserved Hub->AP: Sensor fusion data

Table 2: Communication protocol CMD list

4.3 Power management

There're three power modes of sensor hub designed to achieve maximum battery life as follows.

1. Power off mode

   This is the mode while sensor hub is powered off.

2. Stop mode
   - This is the low power mode for sensor hub to conserve power consumption after power on.
   - Sensor hub should stay in this mode while the wakeup pin is de-asserted.

3. Active mode
   - This is the full power mode.
   - Sensor hub should stay in this mode while the wakeup pin is asserted.

4.4 State machine

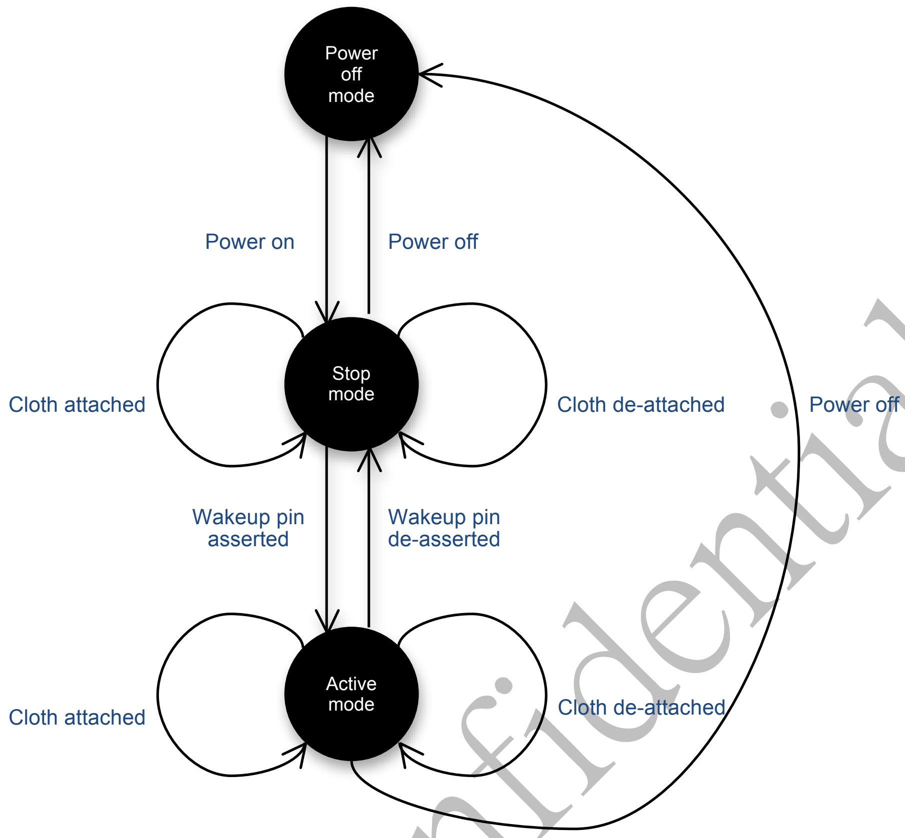

Figure 6: Sensor hub state machine

5. S/W implementation guidelines of application processor

In this chapter, following items are defined.

1. LED bahavior
2. State machine

5.1 LED behavior

There're two LEDs, Green and Red color, and are controlled by two GPIOs of application processor. The two LED can be lighted at the same time with different duty to generate other colors e.g. Orange color. Three colors will be used in our design, Green, Red and Orange. The use cases are defined in following table.

Primary mode	Secondary mode	LED color	LED behavior
Charging	Data transferring (SD card access)	Orange	On 0.5 sec and then off 0.5 sec periodically
	No data transfer		Always on
Fully charged	Data transferring (SD card access)	Orange	On 0.5 sec and then off 0.5 sec periodically
	No data transfer	None	Always off
Power on	N/A	Green	On 3 sec and then off
Power off	N/A	None	Always off
Pairing/ Connecting	N/A	Green	On 0.5 sec and then off 0.5 sec periodically
Paired/ Connected	N/A	Green	On 3 sec and then off
Heart beat	After connected to paired host	Green	On 0.5 sec and then off 9.5 sec periodically
Low battery (<=15%)	N/A	Red	On 0.5 sec and then off 9.5 sec periodically
Encountering error	N/A	Red	Always on

Table 3: LED behavior

5.2 State machine

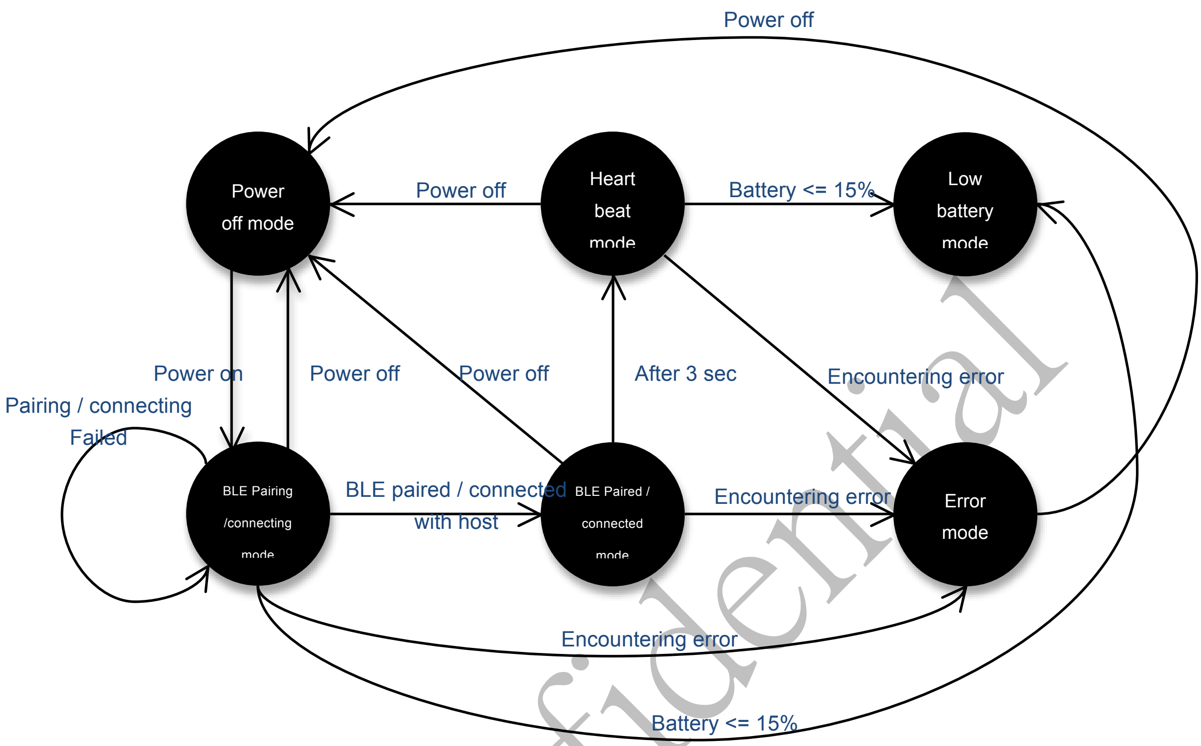

Figure 7: Application processor state machine while not connected to PC/power adapter

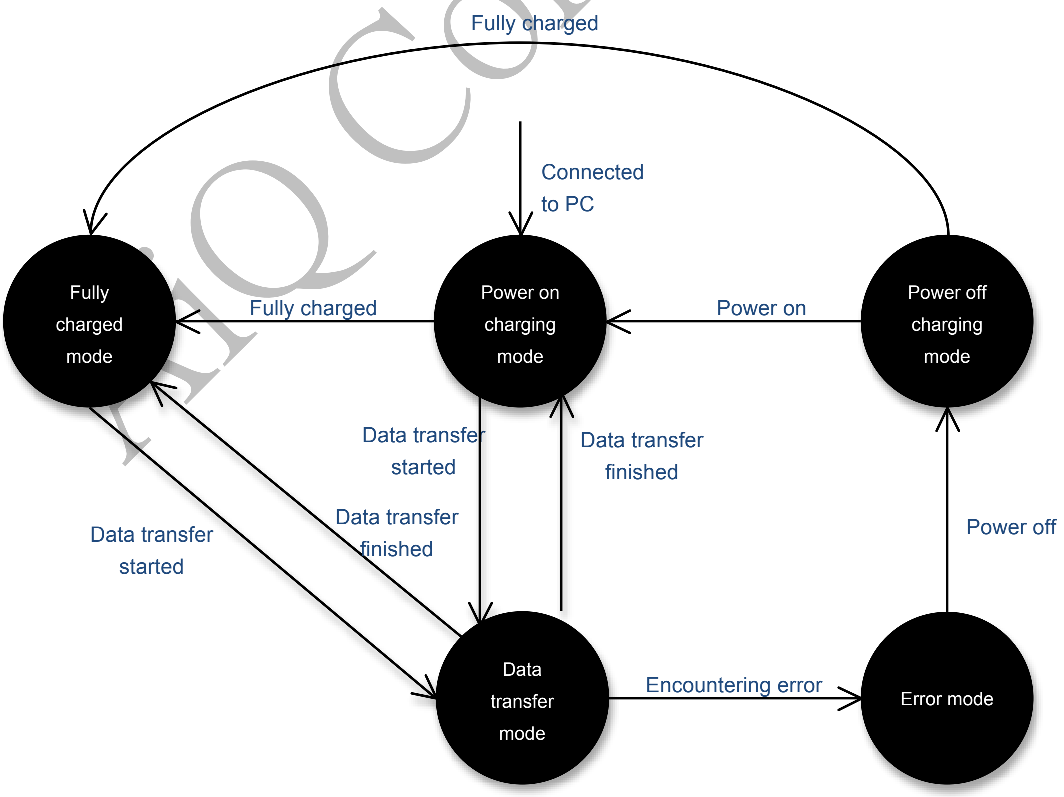

Figure 8: Application processor state machine while connect to PC/power adapter in power on mode

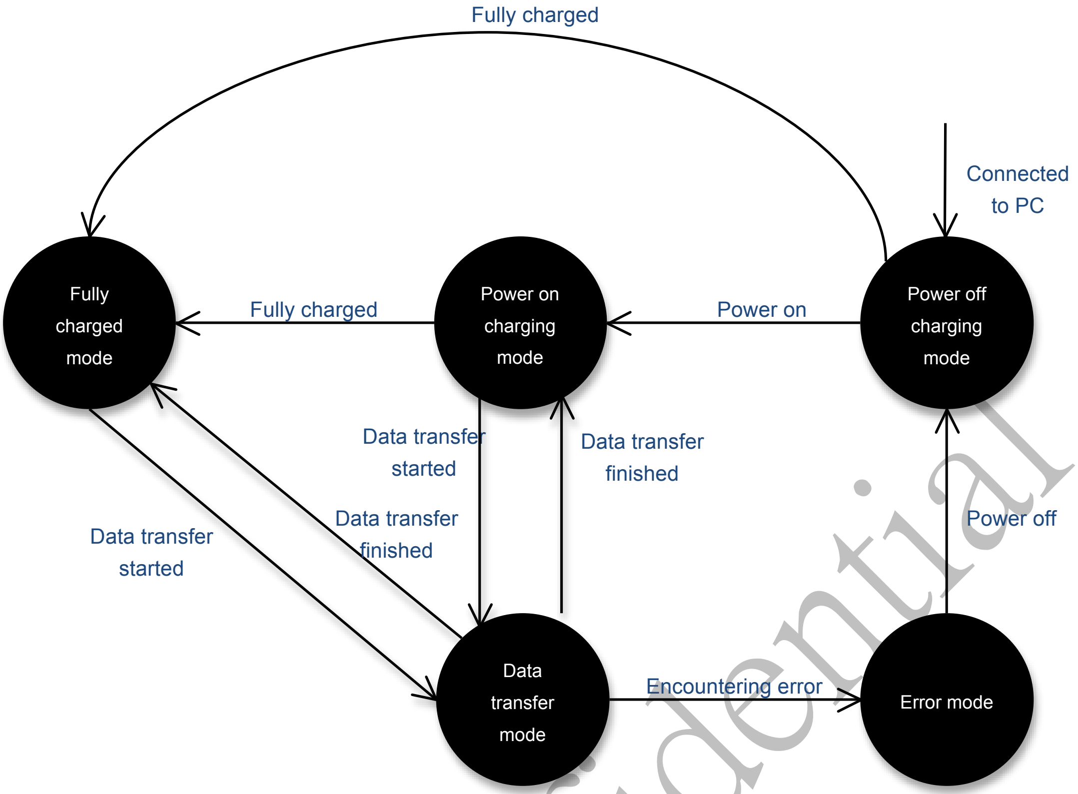

Figure 9: Application processor state machine while connected to PC/power adapter in power off mode

6. F/W update mechanism

The goal is the entire system FW can be updated including application processor and sensor hub as follows.

1. Application processor FW can be updated by OTA (Over-The-Air).
   - Fail-safe mechanism shall be considered. To be added.

2. Sensor hub FW can be included in the APK and APK can update sensor hub FW on demand.
   - Fail-safe mechanism shall be considered. To be added.