短距离无线传输协议程序说明

1. 准备工作

    1) 下载nRF52的SDK 12.1.0 (https://www.nordicsemi.com/eng/nordic/Products/ nRF52832/nRF5-SDK-v12-zip/54281)，解压后准备使用。

    2) 安装好开发环境GCC for ARM "GNU ARM Embedded Toolchain" (https:// launchpad.net/gcc-arm-embedded),包括一些必要的工具如Make，编辑器等。

    3) 在nRF52的SDK的components/toolchain/gcc/Makfile.posix（或者Makfile.windows）文件中，设置好GCC编译器的路径（必要时更进一步设置好环境变量PATH），例如(macOS操作系统中，设置Makfile.posix)

    ```
    GNU_INSTALL_ROOT := /usr/local/gcc-arm-none-eabi-5_4-2016q3
    GNU_VERSION := 5.4.1
    GNU_PREFIX := arm-none-eabi
    ```

    4) 安装好其它一些必要的开发工具如J-link等。

2. 把文件夹"my_project"的所有文件放在nRF52的SDK目录下。例如，下图中SDK是放在目录nRF5_SDK_12_1中，其中"components","documentation"等是SDK的原有文件目录，"my_project"就是短距离无线传输协议程序。
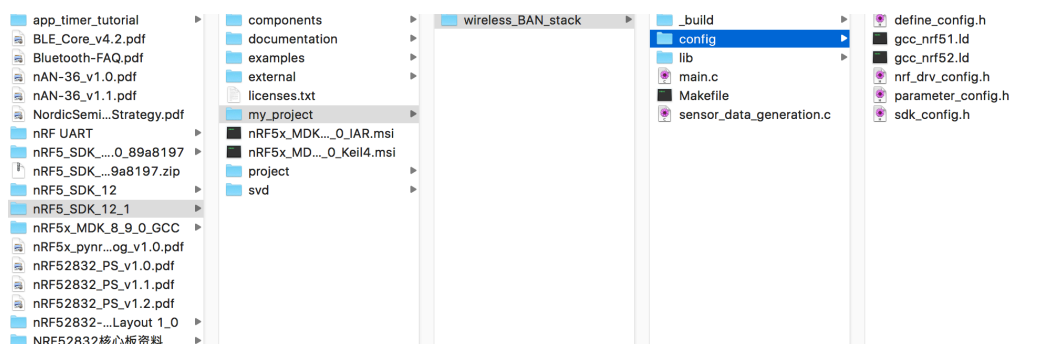
    其中main.c是主函数，config目录是一些参数的设置文件，lib目录是编译好的库函数。而sensor_data_generation.c是一个产生传感器数据的例子程序（目前是产生一个随机数序列）。

3. 发射端（传感器）程序编译方法:

    1) 在文件my_project/wireless_BAN_stack/Makefile中，设置"SENSOR := 1"

    ```
    #/* 1: sensor side, 0: smart phone side */
    SENSOR       :=  1
    ```

    2) 在文件my_project/wireless_BAN_stack/config/define_config.h中，设置"#define SENSOR   1"

```
/* 1: sensor side, 0: smart phone side */
#define SENSOR                    1
```

3) 在命令行窗口及目录my_project/wireless_BAN_stack/中，通过make命令编译程序，得到HEX文件my_project/wireless_BAN_stack/_build/wireless_sim_nrf52832_sensor.hex

```
[localhost:wireless_BAN_stack jiachengwang$ make
 rm -rf _build
 echo  Makefile
 Makefile
 mkdir _build
 Compiling file: nrf_saadc.c
 Compiling file: nrf_drv_saadc.c
 Compiling file: system_nrf52.c
 Compiling file: nrf_drv_common.c
 Compiling file: main.c
 Compiling file: sensor_data_generation.c
 Compiling file: gcc_startup_nrf52.S
 Linking target: wireless_sim_nrf52832_sensor.out
 Preparing: wireless_sim_nrf52832_sensor.bin
 Preparing: wireless_sim_nrf52832_sensor.hex

    text    data     bss     dec     hex filename
   60632    3704    3268   67604   10814 _build/wireless_sim_nrf52832_sensor.out

[localhost:wireless_BAN_stack jiachengwang$ ls -ls _build/
 total 8472
    48 -rw-r--r--  1 jiachengwang  staff   20836 10 27 08:56 gcc_startup_nrf52.o
    16 -rw-r--r--  1 jiachengwang  staff    6128 10 27 08:56 main.d
  1088 -rw-r--r--  1 jiachengwang  staff  556380 10 27 08:56 main.o
    16 -rw-r--r--  1 jiachengwang  staff    7676 10 27 08:56 nrf_drv_common.d
  1120 -rw-r--r--  1 jiachengwang  staff  569836 10 27 08:56 nrf_drv_common.o
    16 -rw-r--r--  1 jiachengwang  staff    7976 10 27 08:56 nrf_drv_saadc.d
  1200 -rw-r--r--  1 jiachengwang  staff  611676 10 27 08:56 nrf_drv_saadc.o
    16 -rw-r--r--  1 jiachengwang  staff    6935 10 27 08:56 nrf_saadc.d
  1112 -rw-r--r--  1 jiachengwang  staff  566200 10 27 08:56 nrf_saadc.o
     8 -rw-r--r--  1 jiachengwang  staff    1248 10 27 08:56 sensor_data_generation.d
    64 -rw-r--r--  1 jiachengwang  staff   29724 10 27 08:56 sensor_data_generation.o
     8 -rw-r--r--  1 jiachengwang  staff    2625 10 27 08:56 system_nrf52.d
  1040 -rw-r--r--  1 jiachengwang  staff  531216 10 27 08:56 system_nrf52.o
   128 -rwxr-xr-x  1 jiachengwang  staff   64336 10 27 08:56 wireless_sim_nrf52832_sensor.bin
   360 -rw-r--r--  1 jiachengwang  staff  180992 10 27 08:56 wireless_sim_nrf52832_sensor.hex
   576 -rw-r--r--  1 jiachengwang  staff  294738 10 27 08:56 wireless_sim_nrf52832_sensor.map
  1656 -rwxr-xr-x  1 jiachengwang  staff  912180 10 27 08:56 wireless_sim_nrf52832_sensor.out
```

4. 发射端（传感器）程序写入nRF52832开发板

1) 擦除nRF52832开发板flash，通过命令"make recover"。

```
localhost:wireless_BAN_stack jiachengwang$ pwd
/Users/jiachengwang/Desktop/My_document/Nordic/nRF5_SDK_12_1/my_project/wireless_BAN_stack
localhost:wireless_BAN_stack jiachengwang$ make recover
nrfjprog --recover -f nrf52
Recovering device. This operation might take 30s.
Erasing user code and UICR flash areas.
```

2) 把程序写入nRF52832开发板，通过命令"make flash"。

```
localhost:wireless_BAN_stack jiachengwang$ make flash
Linking target: wireless_sim_nrf52832_sensor.out
Preparing: wireless_sim_nrf52832_sensor.hex
Flashing: _build/wireless_sim_nrf52832_sensor.hex
nrfjprog --program _build/wireless_sim_nrf52832_sensor.hex -f nrf52 --sectorerase
Parsing hex file.
Erasing page at address 0x0.
Erasing page at address 0x1000.
Erasing page at address 0x2000.
Erasing page at address 0x3000.
Erasing page at address 0x4000.
Erasing page at address 0x5000.
Erasing page at address 0x6000.
Erasing page at address 0x7000.
Erasing page at address 0x8000.
Erasing page at address 0x9000.
Erasing page at address 0xA000.
Erasing page at address 0xB000.
Erasing page at address 0xC000.
Erasing page at address 0xD000.
Erasing page at address 0xE000.
Erasing page at address 0xF000.
Applying system reset.
Checking that the area to write is not protected.
Programing device.
nrfjprog --reset -f nrf52
Applying system reset.
Run.
```

5. 运行发射端（传感器）程序。给nRF52832开发板直接通电就能运行程序，并通过串口 UART打印log信息(bit rate: 115200)，例如

```
Hi, check sensor data to send, NRF_RTC0->COUNTER = 2124367 --------

----------- Time out for connection request, time used = 1003 -----------

++++++++++++++++++++++++++++++++++++++ Hi, connection is not valid ++++++++++++++++++++++++++++++++++++++
Hi, check sensor data to send, NRF_RTC0->COUNTER = 2125642 --------

----------- Time out for connection request, time used = 1003 -----------

++++++++++++++++++++++++++++++++++++++ Hi, connection is not valid ++++++++++++++++++++++++++++++++++++++
Hi, check sensor data to send, NRF_RTC0->COUNTER = 2126917 --------

----------- Time out for connection request, time used = 1003 -----------

++++++++++++++++++++++++++++++++++++++ Hi, connection is not valid ++++++++++++++++++++++++++++++++++++++
Hi, check sensor data to send, NRF_RTC0->COUNTER = 2128192 --------

----------- Time out for connection request, time used = 1003 -----------

++++++++++++++++++++++++++++++++++++++ Hi, connection is not valid ++++++++++++++++++++++++++++++++++++++
Hi, check sensor data to send, NRF_RTC0->COUNTER = 2129467 --------

----------- Time out for connection request, time used = 1003 -----------

++++++++++++++++++++++++++++++++++++++ Hi, connection is not valid ++++++++++++++++++++++++++++++++++++++
Hi, check sensor data to send, NRF_RTC0->COUNTER = 2130742 --------

----------- Time out for connection request, time used = 1003 -----------

++++++++++++++++++++++++++++++++++++++ Hi, connection is not valid ++++++++++++++++++++++++++++++++++++++
Hi, check sensor data to send, NRF_RTC0->COUNTER = 2132017 --------
```

程序检查是否有数据需要传输，并向接收端发出连接请求。（在上面的例子中，由于没有接收端，所以没有能够建立连接）

6. 接收端（智能手机）程序编译方法：

1) 在文件my_project/wireless_BAN_stack/Makefile中，设置"SENSOR := 0"

```
#/* 1: sensor side, 0: smart phone side */
SENSOR        := 0
```

2) 在文件my_project/wireless_BAN_stack/config/define_config.h中，设置"#define SENSOR　　　0"

```
/* 1: sensor side, 0: smart phone side */
#define SENSOR                    0
```

3) 在命令行窗口及目录my_project/wireless_BAN_stack/中，通过make命令编译程序，得到HEX文件my_project/wireless_BAN_stack/_build/wireless_sim_nrf52832_phone.hex

```
[localhost:wireless_BAN_stack jiachengwang$ make
rm -rf _build
echo  Makefile
Makefile
mkdir _build
Compiling file: nrf_saadc.c
Compiling file: nrf_drv_saadc.c
Compiling file: system_nrf52.c
Compiling file: nrf_drv_common.c
Compiling file: main.c
Compiling file: sensor_data_generation.c
Compiling file: gcc_startup_nrf52.S
Linking target: wireless_sim_nrf52832_phone.out
Preparing: wireless_sim_nrf52832_phone.bin
Preparing: wireless_sim_nrf52832_phone.hex

   text    data     bss     dec     hex filename
  62696    3796    3048   69540   10fa4 _build/wireless_sim_nrf52832_phone.out

[localhost:wireless_BAN_stack jiachengwang$ ls -l _build/
total 8496
-rw-r--r--  1 jiachengwang  staff   20836 10 27 09:06 gcc_startup_nrf52.o
-rw-r--r--  1 jiachengwang  staff    6032 10 27 09:06 main.d
-rw-r--r--  1 jiachengwang  staff  555072 10 27 09:06 main.o
-rw-r--r--  1 jiachengwang  staff    7676 10 27 09:06 nrf_drv_common.d
-rw-r--r--  1 jiachengwang  staff  569836 10 27 09:06 nrf_drv_common.o
-rw-r--r--  1 jiachengwang  staff    7976 10 27 09:06 nrf_drv_saadc.d
-rw-r--r--  1 jiachengwang  staff  611676 10 27 09:06 nrf_drv_saadc.o
-rw-r--r--  1 jiachengwang  staff    6935 10 27 09:06 nrf_saadc.d
-rw-r--r--  1 jiachengwang  staff  566200 10 27 09:06 nrf_saadc.o
-rw-r--r--  1 jiachengwang  staff    1248 10 27 09:06 sensor_data_generation.d
-rw-r--r--  1 jiachengwang  staff   29724 10 27 09:06 sensor_data_generation.o
-rw-r--r--  1 jiachengwang  staff    2625 10 27 09:06 system_nrf52.d
-rw-r--r--  1 jiachengwang  staff  531216 10 27 09:06 system_nrf52.o
-rwxr-xr-x  1 jiachengwang  staff   66492 10 27 09:06 wireless_sim_nrf52832_phone.bin
-rw-r--r--  1 jiachengwang  staff  187076 10 27 09:06 wireless_sim_nrf52832_phone.hex
-rw-r--r--  1 jiachengwang  staff  294099 10 27 09:06 wireless_sim_nrf52832_phone.map
-rwxr-xr-x  1 jiachengwang  staff  911036 10 27 09:06 wireless_sim_nrf52832_phone.out
```

7. 通过如上所述4相同的方法，把接收端（智能手机）程序写入另外一个nRF52832开发板。

8. 运行接收端（智能手机）程序,log信息如下（没有发射端程序运行，所以没有收到数据）

```
Hi, No sensor data received, NRF_RTC0->COUNTER = 79254 --------
Hi, No sensor data received, NRF_RTC0->COUNTER = 79516 --------
Hi, No sensor data received, NRF_RTC0->COUNTER = 79778 --------
Hi, No sensor data received, NRF_RTC0->COUNTER = 80040 --------
Hi, No sensor data received, NRF_RTC0->COUNTER = 80302 --------
Hi, No sensor data received, NRF_RTC0->COUNTER = 80564 --------
Hi, No sensor data received, NRF_RTC0->COUNTER = 80826 --------
Hi, No sensor data received, NRF_RTC0->COUNTER = 81088 --------
Hi, No sensor data received, NRF_RTC0->COUNTER = 81350 --------
Hi, No sensor data received, NRF_RTC0->COUNTER = 81612 --------
Hi, No sensor data received, NRF_RTC0->COUNTER = 81874 --------
Hi, No sensor data received, NRF_RTC0->COUNTER = 82136 --------
==================== Wireless On, Not connected, CONNECTION_STATE = 4, ====================
Hi, No sensor data received, NRF_RTC0->COUNTER = 82406 --------
Hi, No sensor data received, NRF_RTC0->COUNTER = 82669 --------
Hi, No sensor data received, NRF_RTC0->COUNTER = 82931 --------
Hi, No sensor data received, NRF_RTC0->COUNTER = 83193 --------
Hi, No sensor data received, NRF_RTC0->COUNTER = 83455 --------
Hi, No sensor data received, NRF_RTC0->COUNTER = 83717 --------
Hi, No sensor data received, NRF_RTC0->COUNTER = 83979 --------
Hi, No sensor data received, NRF_RTC0->COUNTER = 84241 --------
Hi, No sensor data received, NRF_RTC0->COUNTER = 84503 --------
Hi, No sensor data received, NRF_RTC0->COUNTER = 84765 --------
```

9. 同时运行发射端（传感器）程序和接收端（智能手机）程序，演示数据包的无线传输和接收。

   1) 发射端（传感器）程序log信息

```
-------------------------- Data carrier frequency = 65, Logical address = 1, --------------------------
==================== Wireless On, Connected, CONNECTION_STATE = 3  ====================
Hi, check sensor data to send, NRF_RTC0->COUNTER = 5720 --------

-------------------------- Data carrier frequency = 1, Logical address = 1, --------------------------
Transmitted_length=32: 0, cc, 0, 0, aa, 20, 30, 0, 10, 20, 20, 0, 0, 0, 0, 0, 0, 0, 0, 0, 5, 9, 3, d4, 5b, 5f, e9, c0, 27, e0, 86,
-------------------- sensor data send successfully --------------------
Hi, check sensor data to send, NRF_RTC0->COUNTER = 6081 --------
Hi, check sensor data to send, NRF_RTC0->COUNTER = 6336 --------
Hi, check sensor data to send, NRF_RTC0->COUNTER = 6590 --------
Hi, check sensor data to send, NRF_RTC0->COUNTER = 6844 --------
Hi, check sensor data to send, NRF_RTC0->COUNTER = 7099 --------
Hi, check sensor data to send, NRF_RTC0->COUNTER = 7353 --------
Hi, check sensor data to send, NRF_RTC0->COUNTER = 7607 --------
Hi, check sensor data to send, NRF_RTC0->COUNTER = 7862 --------
Hi, check sensor data to send, NRF_RTC0->COUNTER = 8116 --------

-------------------------- Data carrier frequency = 26, Logical address = 1, --------------------------
==================== Wireless On, Connected, CONNECTION_STATE = 3  ====================
Hi, check sensor data to send, NRF_RTC0->COUNTER = 8488 --------
Hi, check sensor data to send, NRF_RTC0->COUNTER = 8743 --------
Hi, check sensor data to send, NRF_RTC0->COUNTER = 8997 --------
Hi, check sensor data to send, NRF_RTC0->COUNTER = 9251 --------
Hi, check sensor data to send, NRF_RTC0->COUNTER = 9506 --------
Hi, check sensor data to send, NRF_RTC0->COUNTER = 9760 --------
Hi, check sensor data to send, NRF_RTC0->COUNTER = 10014 --------
Hi, check sensor data to send, NRF_RTC0->COUNTER = 10269 --------
Hi, check sensor data to send, NRF_RTC0->COUNTER = 10523 --------
Hi, check sensor data to send, NRF_RTC0->COUNTER = 10778 --------

-------------------------- Data carrier frequency = 23, Logical address = 1, --------------------------
==================== Wireless On, Connected, CONNECTION_STATE = 3  ====================
Hi, check sensor data to send, NRF_RTC0->COUNTER = 11168 --------
Hi, check sensor data to send, NRF_RTC0->COUNTER = 11423 --------

-------------------------- Data carrier frequency = 66, Logical address = 1, --------------------------
Transmitted_length=32: 0, cc, 0, 0, aa, 0, 30, 10, 10, 10, 10, 0, 0, 0, 0, 0, 0, 0, 0, 0, 5, 9, 4, a5, eb, a2, eb, 5d, f1, 6e, e1,
-------------------- sensor data send successfully --------------------
Hi, check sensor data to send, NRF_RTC0->COUNTER = 11795 --------
Hi, check sensor data to send, NRF_RTC0->COUNTER = 12050 --------
```

   2) 接收端（智能手机）程序log信息

```
-------------------- Data carrier frequency = 65, Logical address = 1, Connection type = 17,  --------------------
==================== Wireless On, Connected, CONNECTION_STATE = 7 ====================
Hi, No sensor data received, NRF_RTC0->COUNTER = 175301 --------
Hi, No sensor data received, NRF_RTC0->COUNTER = 175564 --------

-------------------- Data carrier frequency = 1, Logical address = 1, Connection type = 0,  --------------------
Received_length=32: 0, cc, 0, 0, aa, 20, 30, 0, 10, 20, 20, 0, 0, 0, 0, 0, 0, 0, 0, 0, 5, 9, 3, d4, 5b, 5f, e9, c0, 27, e0, 86,
==================== Wireless On, Connected, CONNECTION_STATE = 7 ====================
Hi, No sensor data received, NRF_RTC0->COUNTER = 175908 --------
Hi, No sensor data received, NRF_RTC0->COUNTER = 176171 --------
Hi, No sensor data received, NRF_RTC0->COUNTER = 176433 --------
Hi, No sensor data received, NRF_RTC0->COUNTER = 176695 --------
Hi, No sensor data received, NRF_RTC0->COUNTER = 176957 --------
Hi, No sensor data received, NRF_RTC0->COUNTER = 177219 --------
Hi, No sensor data received, NRF_RTC0->COUNTER = 177481 --------
Hi, No sensor data received, NRF_RTC0->COUNTER = 177743 --------

-------------------- Data carrier frequency = 26, Logical address = 1, Connection type = 17,  --------------------
==================== Wireless On, Connected, CONNECTION_STATE = 7 ====================
Hi, No sensor data received, NRF_RTC0->COUNTER = 178030 --------
Hi, No sensor data received, NRF_RTC0->COUNTER = 178293 --------
Hi, No sensor data received, NRF_RTC0->COUNTER = 178555 --------
Hi, No sensor data received, NRF_RTC0->COUNTER = 178817 --------
Hi, No sensor data received, NRF_RTC0->COUNTER = 179079 --------
Hi, No sensor data received, NRF_RTC0->COUNTER = 179341 --------
Hi, No sensor data received, NRF_RTC0->COUNTER = 179603 --------
Hi, No sensor data received, NRF_RTC0->COUNTER = 179865 --------
Hi, No sensor data received, NRF_RTC0->COUNTER = 180127 --------
Hi, No sensor data received, NRF_RTC0->COUNTER = 180389 --------

-------------------- Data carrier frequency = 23, Logical address = 1, Connection type = 17,  --------------------
==================== Wireless On, Connected, CONNECTION_STATE = 7 ====================
Hi, No sensor data received, NRF_RTC0->COUNTER = 180673 --------
Hi, No sensor data received, NRF_RTC0->COUNTER = 180936 --------
Hi, No sensor data received, NRF_RTC0->COUNTER = 181198 --------

-------------------- Data carrier frequency = 66, Logical address = 1, Connection type = 0,  --------------------
Received_length=32: 0, cc, 0, 0, aa, 0, 30, 10, 10, 10, 10, 0, 0, 0, 0, 0, 0, 0, 0, 0, 5, 9, 4, a5, eb, a2, eb, 5d, f1, 6e, e1,
==================== Wireless On, Connected, CONNECTION_STATE = 7 ====================
Hi, No sensor data received, NRF_RTC0->COUNTER = 181543 --------
Hi, No sensor data received, NRF_RTC0->COUNTER = 181805 --------
```

10. my_project/wireless_BAN_stack/sensor_data_generation.c是一个产生传感器数据的例子程序，只要把需要传输的数据包写入全局变量SENSOR_DATA（数组）就可以了。其中

SENSOR_DATA[0]是数据包的序号，SENSOR_DATA[1]是数据包的长度。SENSOR_DATA[2]是数据包的传感器数据类型，目前有5种数据类型，包括体温，心率，心电，血压，血氧。而从SENSOR_DATA[3]开始的数据SENSOR_DATA[3],SENSOR_DATA[3],SENSOR_DATA[4],……,就是需要传输的传感器数据。

11. 接收端（智能手机）接收到各种传感器数据后，包括体温、心率、心电图数据、血压、血氧，就分别存入全局变量BODY_TEMPERATURE，HEART_RATE，ECG_VALUE，BLOOD_PRESURE，BLOOD_OXYGEN。这些变量都是byte数组，如果传感器数据是浮点数，需要先转化成二进制的byte数组，再进行无线传输。其中BODY_TEMPERATURE[0]是数组BODY_TEMPERATURE的byte数据长度，BODY_TEMPERATURE[1]是传感器数据类型SENSOR_DATA_TYPE_BODY_TEMPERATURE（在define_config.h中定义），而接收到的体温数据是BODY_TEMPERATURE[2]，BODY_TEMPERATURE[3],……。其它的传感器数据格式类似。

```c
/* sensor data of body temperature
|  index 0:  data length, 0 ~ 255
|  index 1:  data type, SENSOR_DATA_TYPE_BODY_TEMPERATURE
|  index 2 ~ : sensor data of body temperature */
extern uint8_t BODY_TEMPERATURE[256];
```
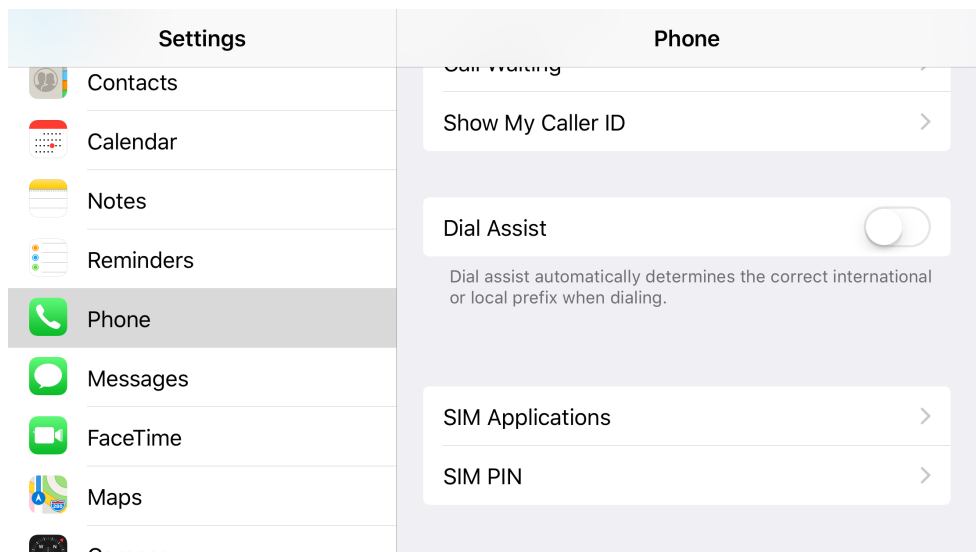
12. 主函数main.c中有有2个全局变量，PHONE_CHIP_TYPE和UART_LOG，用于配置程序。

```c
/* Phone side chip type
* 0: MTK chip, the SIM clock frequency is 3.25MHz
* 1: QCM chip, the SIM clock frequency is 3.84MHz */
uint8_t PHONE_CHIP_TYPE = 0;

/* if log information is forward to UART
* 0: no log information to UART
* 1: log information to UART */
uint8_t UART_LOG = 1;
```

1) PHONE_CHIP_TYPE是针对接收端（智能手机）的芯片类型。如果智能手机是高通（QCM）通信芯片（例如iPhone，小米6等），就设置为PHONE_CHIP_TYPE = 1。如果智能手机是联发科（MTK）通信芯片，就设置为PHONE_CHIP_TYPE=0。

2) UART_LOG是针对LOG信息的输出。如果设置UART_LOG = 1，当程序则在nRF52832开发板运行时，其UART有LOG信息输出。如果设置UART_LOG = 0，当程序则在nRF52832开发板运行时，则UART没有LOG信息输出。

13. 在接收端（智能手机），可以把接收到的传感器数据在智能手机的屏幕上显示出来。目前应用SIM卡应用程序接口，等待智能手机的应用程序APP开发完成后，就可以应用程序APP中显示。

1) 以iPhon为例，其SIM卡应用程序在设置-手机-SIM卡应用程序

Settings	Phone
Contacts	Show My Caller ID >
Calendar	
Notes	Dial Assist ⚪
Reminders	Dial assist automatically determines the correct international or local prefix when dialing.
Phone	
Messages	SIM Applications >
FaceTime	SIM PIN >
Maps	
Compass	

2) 点击SIM卡应用程序，就显示传感器数据类型菜单

Settings	‹ Phone SIM Applications
Contacts	BODY SENSOR DATA
Calendar	body temperature
Notes	heart rate
Reminders	ECG value
Phone	blood presure
Messages	blood oxygen
FaceTime	
Maps	
Compass	
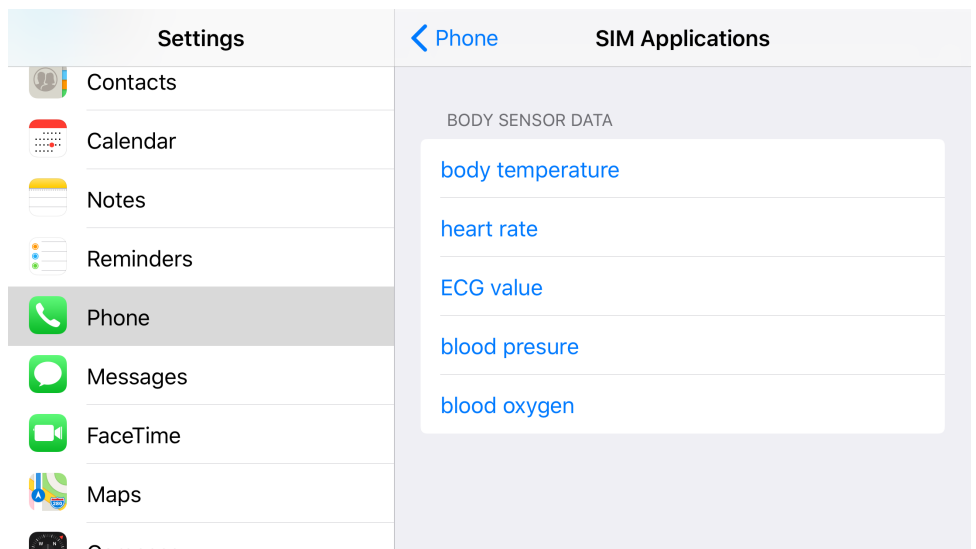
3) 点击传感器数据类型菜单，就显示其最新接收到的传感器数据

Settings

Back

Contacts

Calendar

Notes

Reminders

BODY SENSOR DATA

body temperature

heart rate

Phone

Body Temperature: 0ebb5f5f181c58be

Messages

blood presure

FaceTime

Cancel

blood oxygen

Accept

Maps