Data Handling

Máster Universitario en Sistemas Espaciales

Native and Cross-Development Environment Work

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2nd student assignment

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Contents

Introduction

This document provides instructions for laboratory work in the field of embedded systems. The laboratory is part of the Data Handling course of the UPM Máster Universitario de Sistemas Espaciales (MUSE) program. The laboratory is based on a computer kit that is used to build a simplified version of a satellite on-board software system (OBSW). An instance of the laboratory kit will be made available to every student registered in the course during the laboratory session.

Students are required to use their own personal computer, running Windows, MacOS, or GNU/Linux, to carry out the laboratory assignments. The outline of the laboratory assignments to be carried out is as follows:

1. Installation of a native programming environment.
2. Installation of the cross-platform programming tools.
3. Simple housekeeping program.
4. Tasking program.
5. Distributed program.
6. Real-time program, including temporal analysis
7. Real-time program with Attitude Control System.
8. On-board data handling (OBDH) system.

References

The following documents contain additional information about the software and hardware tools used to develop the work:

Hardware

1. STMicroelectronics. DB1421 Data Brief. STM32F4DISCOVERY - Discovery kit with STM32F407VG MCU.
2. STMicroelectronics. UM1472 User manual - Discovery kit with STM32F407VG MCU.
3. STMicroelectronics. DS 8626. Data sheet - STM32F405xx, STM32F407xx. ARM Cortex-M4 32b MCU+FPU, 210DMIPS, up to 1MB Flash/192+4KB RAM, USB OTG HS/FS, Ethernet, 17 TIMs, 3 ADCs, 15 comm. interfaces & camera.
4. STMicroelectronics. RM0090 Reference manual - STM32F405/415, STM32F407/417, STM32F427/437 and STM32F429/439 advanced Arm©-based 32-bit MCUs.

Software

The following manuals are available from the "Help" menu in the GNAT Programming Studio (GPS):

1. Ada Reference Manual.
2. GPS User's Guide.

3. GNAT User's Guide for Native Platforms.
4. GNAT User's Guide Supplement for Cross Platforms
5. GNAT Reference Manual.

Acronyms

ADC	Analog to Digital Converter.
ACS	Attitude Control System.
DAC	Digital to Analog Converter.
FPU	Floating Point Unit.
GCC	GNU compilation system..
GDB	GNU Debugger.
GNAT	GNU Ada Translator.
GNU	GNU is not Unix.
GPL	GNU Public License.
GPS	GNAT Programming Studio.
LGPL	Lesser GNU Public License (formerly Library GPL).
MCU	Microcontroller Unit.
OBC	On-Board Computer.
OBDH	On-Board Data Handling.
OBSW	On-Board Software.
OS	Operating System.
PC	IBM Personal Computer architecture.
TC	Telecommand.
TM	Telemetry.
USART	Universal Synchronous Asynchronous Receiver Transmitter.
USB	Universal Serial Bus.

Overview

Laboratory kit components

The laboratory kit includes:

- An STM32F407 computer board, which emulates an on-board computer system (OBC).
- A USB A / mini USB cable which is used to connect the OBC board to the development station hosted on the student PC.
- A USB / UART interface cable which is used to provide a serial line link between the OBC board and the ground station software running on the student PC.

Figure 1 shows the components of the laboratory kit and the connections to the student PC.

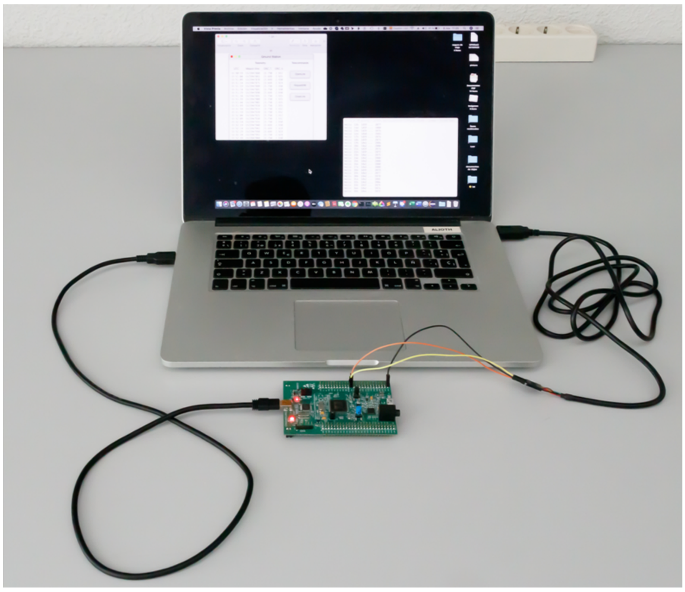


Figure 1: Laboratory kit.

Architecture of the laboratory platform

The components of the laboratory kit are used to emulate a simplified version of a satellite on-board software system. Figure 2 shows the architecture of the laboratory system.

The system consists of a flight segment, implemented on the laboratory computer board, and a ground system, implemented on the student PC. The communication between both segments is carried out by means of a serial line, simulating the radio link of a real satellite mission. The student work is centered on programming the computer board. The ground station software will be provided by the teachers.

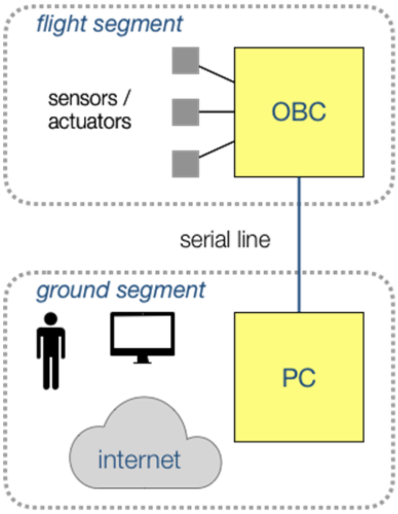


Figure 2: Architecture of the laboratory system.

Computer board and connections

The STM32F407 board is used as a low-cost replacement for a satellite on-board computer (OBC). The board features a 32-bit ARM Cortex-M4 microcomputer, 192 KB RAM, 1 MB Flash memory and a number of other devices.

Figure 3 shows an overall view of the computer board.

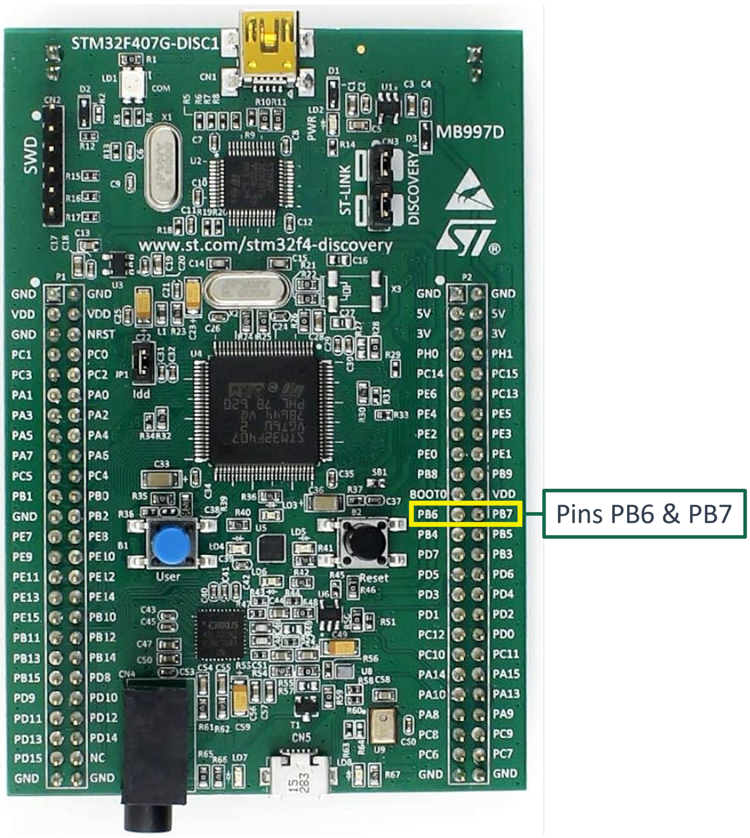


Figure 3: Computer board.

The following are the main components used in this laboratory:

- USB ST-LINK connector, which is linked to a PC with a mini-USB to USB-A cable. This connection is used to supply power to the board (5 V) and load and debug the software from the host PC.

- General Purpose Input-Output (GPIO) pins PB6, PB7 and GND. GPIO is a standard interface for connecting external devices. These GPIO pins are used in the laboratory to connect a serial line to a USB port on a PC, emulating the connection to the on-board radio equipment in a satellite. Specifically the pin:
  - **PB6** is used as the transmitter pin (TX).
  - **PB7** is used as the receiver pin (RX).
  - **GND** is used for grounding.
- Temperature and voltage sensors. These sensors are part of the STM32 microcomputer chip, and can be read using internal registers in the MCU. They are used in the laboratory to emulate the housekeeping devices onboard the satellite.

Assignment 1

Install a native programming environment

The aim of this assignment is to install a native programming environment for the Ada language on the student PC. This environment will later be extended with cross-compilation tools for the STM32 board to be used in the laboratory.

The programming environment to be used is GNAT Community, an open-source software development environment freely available from AdaCore, a company specialised in providing tools and solutions for developing high-integrity software,

1.0.1 Download and install GNAT

The GNAT Community compilation system can be downloaded from `https://www.adacore.com/download/more`. Installation packages for Windows, MacOS and GNU Linux are available at the download page. The file `README.txt` provides installation instructions, which are summarized in the following subsections:

Windows

1. Download the file `gnat-2021-20210519-x86_64-windows64-bin.exe`
2. Run the file and follow the instructions.

Important: GNATStudio installs additional configuration files in the `.gnatstudio` folder, which is located under your Home directory (e.g.: `C:\\user_name\.gnatstudio`). Notice that the application will not start if your user account contains special character such as spaces or accent marks. Then, to solve this you must remove all special characters from your user account. This link provides detailed instructions to solve this issue.

MacOS

1. Download the file `gnat-2020-20200818-x86_64-darwin-bin.dmg`
2. Open the dmg disk and execute the application inside it. In order to circumvent the system protection, control-click on the file and then click on "opens" in the emergent window.

Notice that you need to have installed the Xcode application to install GNAT. If you still see the following error:

```
ld: library not found for -lSystem
```

then you might have to execute the following:

```
xcode-select -s /Applications/Xcode.app/Contents/Developer
```

GNU Linux

1. Download the file `gnat-2021-20210519-x86_64-linux-bin`
2. You will need provide execution permissions to the binary in order to run it. Run the following command in your terminal:

   ```
   chmod +x path_to_the_package.bin
   ```

   and execute the package. The `README.txt` file contains additional installation and execution instructions.

1.1 Test the installation with a simple program

The GNAT compilation system includes the GPS (GNAT programming studio) programming environment, which allows users to edit, compile, and run Ada and C programs. Figure1.1 shows the main GPS window, which is composed of the following areas:

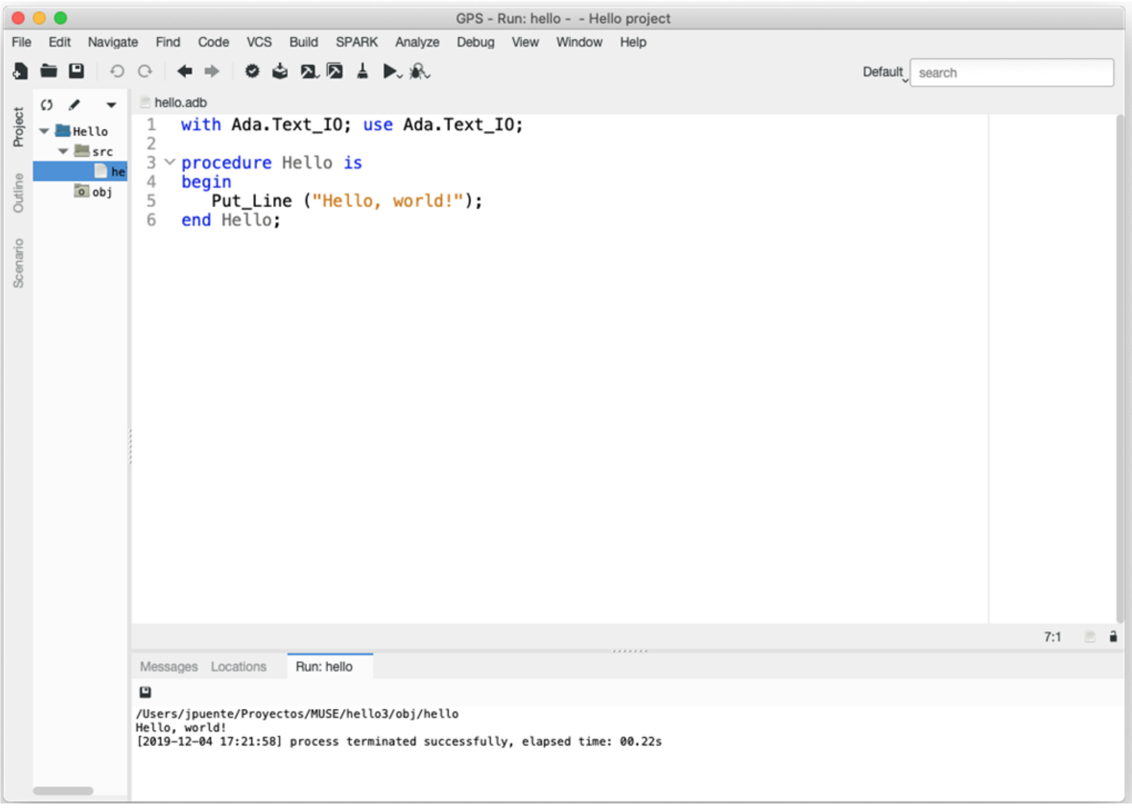


Figure 1.1: GNAT Programming Studio (GPS).

- a menu bar at the top
- a tool bar under the menu bar
- on the left, a notebook allowing you to switch between Project, Outline and Scenario views
- the working area in the center
- the messages window at the bottom

GPS organizes source code in projects. A project is a set of source files which are compiled together in order to produce a single binary executable. Before starting you will need to create a folder to store your software projects. The recommendation is to create a folder named OBDH_LABS in a directory of your choice. The next activity is to write and run a simple Ada program using GPS:

1. Create a new project by clicking on `File` → `New Project` ... in the top menu. Choose the `Simple Ada Project` template.
2. Choose a folder to deploy the project, e.g. OBDH_LABS/LAB1. Set the project name to `Hello` and the main name also to `Hello`.
3. Double click on the `hello.adb` file in the project view to open the file in the working area.
4. Edit the file in the working area so that it has the same content as in figure1.1.
5. Build and run the executable by clicking on the ▷ symbol in the tool bar. You should see a number of compilation-related messages and, if everything is right, you will see the text "Hello, world!" in the Run tab of the bottom window.

Assignment 2

Install the cross-compilation tools

The aim is to get acquainted with the embedded computer board and to install and test the cross-compilation tools for GNAT that will be used to develop executable code for it.

2.1 Cross-compilation tools

The computer board will be programmed in Ada. The GNAT cross-platform software development system will be used (figure 2.1), where the student PC is the host platform and the SMT32 board is the target platform.

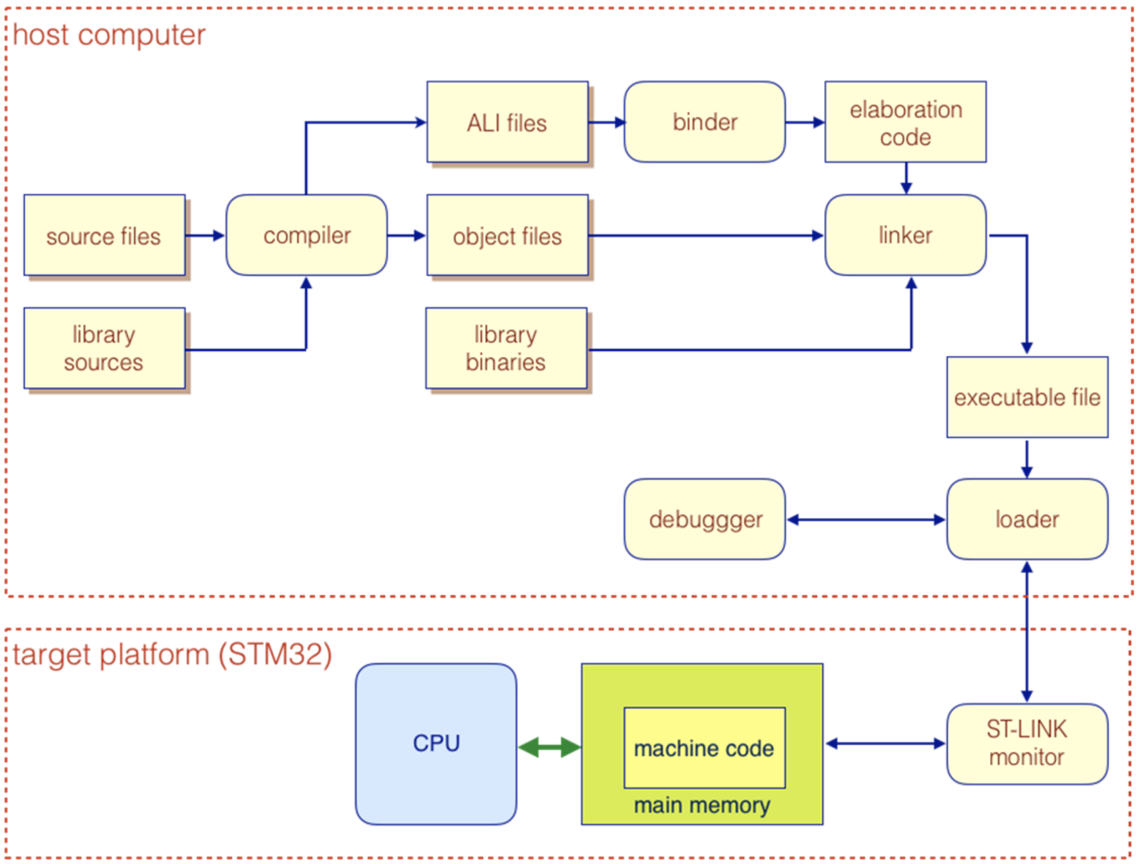


Figure 2.1: Cross-compilation and debugging system

In order to compile a program, the compilation chain is run on the host computer to produce an executable file for the target computer. The executable is then loaded into the target memory, from where it can be run. A monitor program is preinstalled on the target board that supports loading and debugging from the host platform.

2.2 Download and install GNAT ARM ELF

GNAT ARM ELF is the cross-compilation chain to be used with the STM32F4 board. It can be downloaded from the same page as the native GNAT system, and there are installation packages for Windows, MacOS and GNU Linux available. The file `README.txt` provides installation instructions, which are summarized as follows.

Windows

1. Select the platform ARM ELF (hosted on windows64) 2021, and download the file gnat-2021-20210519-arm-elf-windows64-bin.exe
2. Run the file and follow the instructions.
3. You will also need to install the USB driver for the ST-LINK probe. To do so, go to `http://www.st.com/content/st_com/en/products/embedded-software/development-tool-software/stsw-link009.html`, and click on Get Software. Click on Get Software under the Download column of the table that shows up to obtain the driver. You will need to accept ST Micro's license agreement and enter your contact details. Once downloaded unzip the USB device driver and run the installer, accepting all the defaults.

MacOS

1. Select the platform ARM ELF (hosted on darwin) 2021, and download the file gnat-community-2019-20190517-arm-elf-darwin-bin.dmg
2. Open the dmg disk and execute the application inside it. In order to circumvent the system protection, control-click on the file and then click on "open" in the emergent window.
3. You will also need the st-util, st-flash, and st-info tools. You can download the binaries from `https://github.com/texane/stlink/releases/download/1.3.0/stlink-1.3.0-macosx-amd64.zip`. Unzip and copy the files in the bin directory to a directory in your PATH. You may need to circumvent MacOS protection by executing the command:

   $ xattr -d com.apple.quarantine path-to-executable-file

GNU Linux

1. Select the platform ARM ELF (hosted on linux) 2021, and download the file gnat-2021-20210519-arm-elf-linux64-bin
2. You will need to make the package executable before running it. In a command prompt, execute the following command:

   chmod +x path_to_the_package.bin

   and then execute the package.
3. You will also need to install the stlink tools. In Ubuntu and Debian stlink must be installed from sources. Follow the instructions on `http://docs.adacore.com/live/wave/gnat_ugx/html/gnat_ugx/gnat_ugx/arm-elf_topics_and_tutorial.html#linux`.

The `README.txt` file contains additional installation and execution instructions.

2.3 Test your installation with an embedded program

The next activity is to compile and run a simple embedded program. This program is only intended to test that the compilation chain and the ST-LINK tools have been properly installed.

Open GPS and do the following:

1. Create a new project by clicking on File → New Project ... in the top menu. Choose the STM324F compatible → LED demo project template.
2. Choose a folder to deploy the project, e.g. `OBDH_LABS/LAB2`. Set the project name to `led_demo` and the main name to `main`. Then, a window with a project including a source files will be opened.
3. Right-click on the project icon on the left side area, and choose `Project` → `Properties`. On the emerging window, select Embedded and change the Connection tool selector to st-util. Save the settings.
4. Connect the STM32F4 board to the computer by means of a USB-A to mini-USB cable.
5. Build the executable and load it into the board by clicking on the symbol in the tool bar (or select `Build` → `Bareboard` → `Flash to board` on the top menu). You should see a number of compilation-related messages ending with `"Flashing complete. You may need to reset or cycle power"`.
6. If everything is all right, you will see the LEDs on the board blinking in a circular pattern.
7. Download and install the Ada Drivers Library The Ada Drivers Library is a set of Ada packages that make it easier to write software for embedded devices, including the STM32F4 microcontroller family and some demonstration boards. The source code can be found at `https://github.com/AdaCore/Ada_Drivers_Library`. To install the library, click on the green Clone or download button on the upper right side and then on Download Zip in the emerging window. You will get a zip archive in your downloads folder. Unzip the archive and move the resulting folder inside your `OBDH_LABS` folder. Rename the folder to `Ada_Drivers_Library`, removing any trailing text.
8. Compile and run a test program with the Ada Drivers Library

Open GPS and do the following:

1. Select `Open project` on the welcome window. Navigate to

   `.../OBDH_LABS/Ada_Drivers_Library/examples/STM32F4_DISCO`

   and open the project file named `blinky_f4disco.gpr`
2. **Important:** Update the project's runtime to full Ravenscar, as follows: Open `Edit` → `Project properties`; then, inside the `Build` → `Toolchain` → `Ada Runtime` option choose the `ravenscar-full-stm32f4 profile`.
3. Build the executable and load it into the board by clicking on the symbol in the tool bar (or select `Build` → `Bareboard` → `Flash to board` on the top menu). When the loading is complete, you will see the board LEDS blinking all at the same time.

2.4 Install MATLAB™and Simulink™

MATLAB and Simulink will be used to generate C code from a Simulink model and to validate the system by the Processor In the Loop (PIL) technique. The UPM has a campus license available for students. Please read this document to access and install MATLAB with the UPM's license.

Important: Please, consider the following notes:

- The complete installation of MATLAB, including add-ons, requires approximately 10 GB.
- Choose the Individual License, not the Concurrent.
- During the installation procedure, on the 3rd tab of **products**, install the following **add-ons**:
  - MATLAB
  - Simulink
  - MATLAB Coder
  - Simulink Coder
  - Aerospace Toolbox
- After the full installation, the **Embedded Coder** add-on must be installed.

Assignment 3

Simple housekeeping program

The aim of this assignment is to experiment with a simple housekeeping program that only implements a basic function, reading a temperature sensor on the on-board computer. The value read by the sensor is denoted as OBC_T (OBC temperature). The software is organised in modules, in such a way that it can be later extended to a more complex housekeeping system in the next assignments.

3.1 Temperature sensor

The internal temperature sensor in the MCU is used in this assignment. No additional hardware is required.

The STM32F407 reference manual (section 13.10) states that the internal temperature sensor of the MCU is internally cabled to the `ADC1_IN16` analog input channel. The steps required to read the sensor are:

1. Select `ADC1_IN16` input channel in the ADC.
2. Select a sampling time greater than the minimum sampling time specified in the datasheet (see table A.1 below).
3. Set the `TSVREFE` bit in the `ADC_CCR` register to wake up the temperature sensor from power down mode.
4. Start the ADC conversion by setting the `SWSTART` bit (or by external trigger).
5. Read the resulting VSENSE data in the ADC data register.
6. Calculate the temperature using the following formula:

   Temperature (in °C) = (VSENSE - V25) / Avg_Slope + 25

   Where:

   - V25 = VSENSE value for 25 °C (table A.1)
   - Avg_Slope = average slope of the temperature vs. VSENSE curve (table A.1).

The sensor has a startup time after waking from power down mode before it can output VSENSE at the correct level. The ADC also has a startup time after power-on, so to minimize the delay, the `ADON` and `TSVREFE` bits should be set at the same time.

The sensor has a range of -40 to 125 °C, with a precision of ±1.5 °C. Its main characteristics are described in the STM32F407 datasheet (table A.1).

The Ada Drivers Library includes the package STM32.ADC, which provides facilities for handling the analog to digital converter.

Symbol	Parameter	Min	Typ	Max	Unit
TL	VSENSE linearity with temperature	-	± 1	± 2	°C
Avg_Slope	Average slope	-	2.5		mV/°C
V25	Voltage at 25 °C	-	0.76		V
tSTART	Startup time	-	6	10	μs
TS_temp	ADC sampling time when reading the temperature (1 °C accuracy)	10	-	-	μs

Table 3.1: STM32F407 temperature sensor characteristic.

3.2 Software architecture

The software architecture of the simple housekeeping program is depicted in figure 3.1[1]. The software components are:

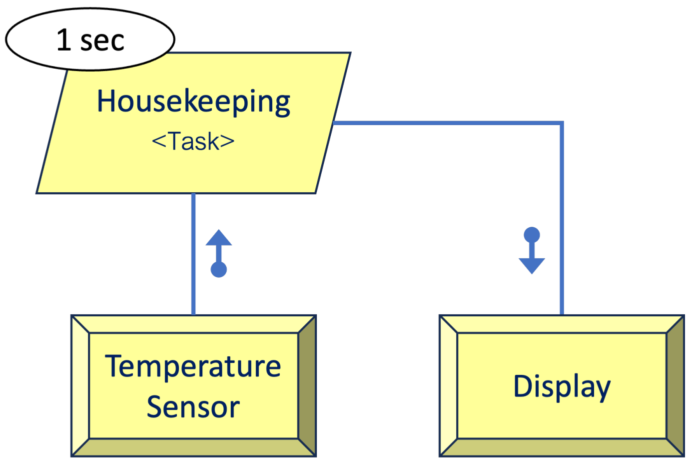


Figure 3.1: Software architecture of simple housekeeping system.

Housekeeping. Main component, which performs the basic functionality of the system, i.e. reading a temperature value and displaying the value on the console.

Sensor. This module provides a high-level interface to the temperature sensor and deals with all the details of reading the ADC to which the sensor is connected.

Display. This module provides a high-level interface to a text console where the measured temperature values can be output.

Since the OBC board does not have a text output device, it has to be simulated on the host computer, using a mechanism called semihosting. When the target board is connected to the host by means of the ST-LINK USB cable, and the embedded program is run using the debugger in the host, the standard output is re-directed to the debugger console. The GPS environment supports semihosting.

3.2.1 Download the code and study the implementation

The implementation code, as initially provided to the students, can be downloaded from

`https://github.com/STR-UPM/SEU-OBDH-Lab`

Click on `<> Code` → `Download ZIP` to download a zip archive, unzip and move it to your working directory. The code for this assignment is in the `LAB3` folder.

[1]The graphic notation is AADL (Architecture Analysis and Design Language).

The `Housekeeping` package is the root element of the housekeeping subsystem. Its specification consists of one procedure, `Initialize`, that starts the operation of the component. It has three subpackages:

Housekeeping.Data contains the definitions of the data types used in the subsystem. Only one data type, `Analog_Data`, is defined for this version of the software.

Housekeeping.Sensor contains the details of the temperature sensor. Its specification includes the `Initialize` and `Get` procedures. This package uses the Ada Drivers Library to interact with the OBC board hardware.

Housekeeping.Display includes the procedure `Put`, which is used to display temperature values on the debugger console (see below). The original implementation of this procedure writes raw sensor values, which are integers in the range 0 to 4095, as directly provided by the ADC hardware. These values have to be converted to engineering units. i.e. degrees Celsius, using the steps shown in section 3.1 above. The software provided to the students includes a program, `adc2celsius`, which implements this functionality.

The `Display.Put` procedure uses the `Ada.Text_IO` package to write to the standard output. Since there is no device that can be used to provide text output on the OBC board, the ST-LINK prove provides a facility, which is called semihosting, to provide this functionality. When the program is run using the cross-debugger on the host, the board standard output is redirected to the debugger console. Therefore, in order to see the temperature values the program must be run from the debugger (see below).

The main procedure is `OBSW`[2]. It calls `Housekeeping.Initialize`, which initializes the sensor and then calls the `Run` procedure. This procedure executes an endless loop that performs the following actions:

- Get a raw temperature measurement from the sensor
- Display the value

Additionally, one of the board LEDs is toggled on and off to provide a visual check that the program is running. Notice that `Run`, and hence `Initialize` and `OBSW`, never return. Therefore the program executes indefinitely, as is common in embedded systems.

3.3 Compile and run with the debugger.

Open GPS and do the following:

1. Select `Open project` on the welcome window. Navigate to the LAB3 directory and open the `simple_housekeeping.gpr` project file.

2. Build the executable and load it into the board by clicking on the  symbol in the tool bar (or select `Build` → `Bareboard` → `Debug` on board on the top menu).

   The program will be compiled, and the executable will be loaded into the board memory by the debugger. After that, the debugger is started[3], and the debugger console (lowest window in GPS) shows the following lines:

   ```
   ...
   (gdb) monitor reset halt
   (gdb)
   ```

3. Type `continue` or just `c` on the debugger console (or select `Debug` → `Continue` on the top menu).

[2]On-Board Software

[3]On Windows a message will be displayed requesting permission to connect st-util to external networks. Be sure to grant such permission to enable the debugger connection to the board.

```
(gdb) c
Continuing.
[program running]
```

4. The program will start running (check the LED blinking), and the raw temperature readings are shown on the `Messages` tab of the debugger console (figure 3.2).

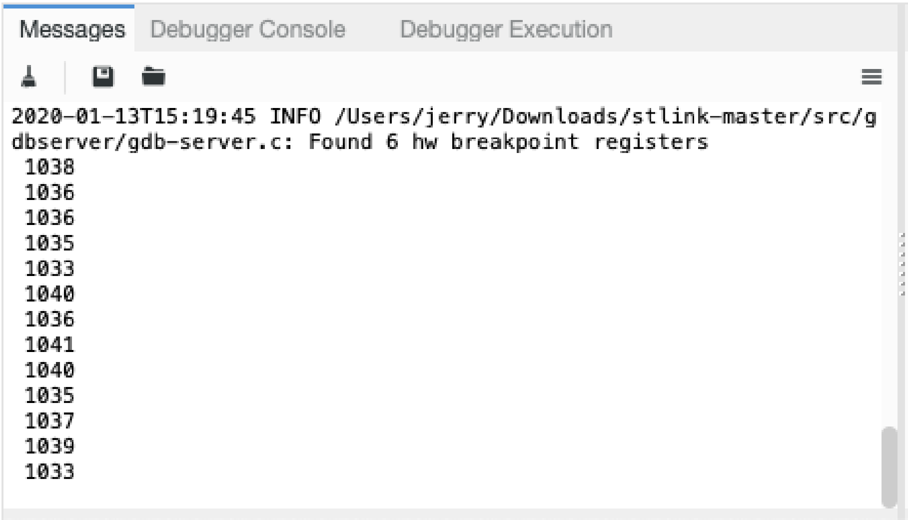


Figure 3.2: Debugger output.

The raw measurement values can be converted to Celsius using the `adc2celsius` program. You should take into account that the internal temperature sensor does not provide an accurate measurement, and may have an offset that varies from one chip to another.

3.4 Make changes to the program

As a final activity, you may make some changes to the provided program in order to make sure that you understand the logics behind the source code. Proposed changes are:

1. Include the conversion to Celsius in the `Display.Put` procedure.
2. Add the following statement to the main loop in the Housekeeping Run procedure:

   `delay until Clock + Milliseconds (1000);`

   The effect of this statement is to delay the execution of the program for 1 s. You will have to import the `Ada.Real_Time` library package in order to use the operations included in the statement.

Assignment 4

Tasking housekeeping program

The aim of this assignment is to extend the simple housekeeping program of the previous assignment by adding a communications subsystem. The extended system includes two concurrent tasks communicating through a protected shared object.

4.1 Software architecture

The software architecture of the tasking housekeeping program is depicted in figure 4.1. The software components are:

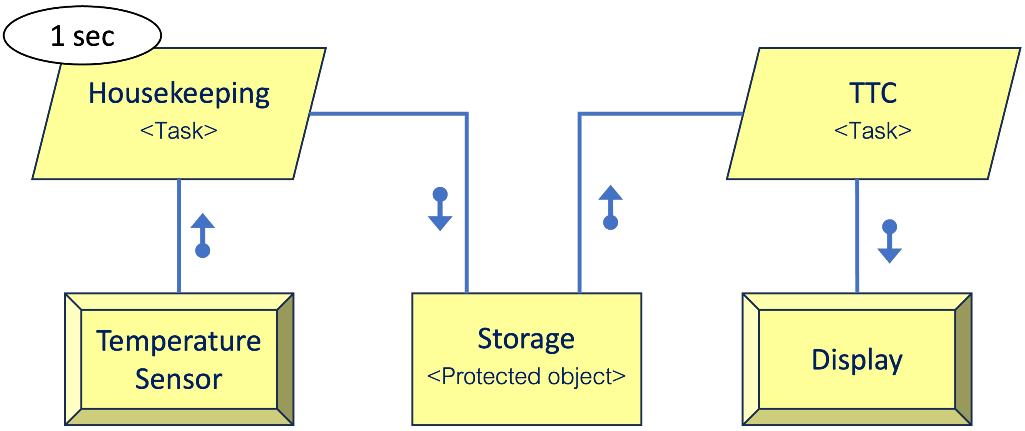


Figure 4.1: Software architecture of tasking housekeeping system.

The differences with the previous architecture are:

- There is a new component, `TTC`, that handles the display.
- Both the `Housekeeping` and `TTC` components include concurrent tasks.
- The `Housekeeping` and `TTC` tasks communicate through a new component, `Storage`. This component is a data object storing one temperature value, which is written by `Housekeeping` and read by `TTC`.

4.1.1 Download the code and study the implementation

The implementation code, as initially provided to the students, can be downloaded from `https://github.com/STR-UPM/OBDH_LABS`. Click on `Clone` or `download`, download a zip archive, unzip and move to your work directory. The code for this assignment is in the LAB4 folder.

As in the previous assignment, the `Housekeeping` package is the root element of the housekeeping subsystem. Its specification and body is similar to the previous version, except that it now contains a concurrent task, `Housekeeping_Task`, and the values read from the sensor are sent to `Storage` instead of `Display`. This package has been moved to the `TTC` subsystem, but otherwise remains similar.

The `TTC` package is the root of the telecommunications system, which in this version is greatly simplified with respect to a real application. It contains a concurrent task, `HK_Task`, which takes measured sensor values from `Storage` and puts them on the display.

The `Storage` package implements the communication between the `Housekeeping` and `TTC` subsystems. Since this object is shared by two concurrent tasks, it is implemented as a protected object, so that its operations are executed in mutual exclusion. There is also conditional synchronization: the `TTC` task must wait until there is a fresh value in the store. However, `Housekeeping` should not wait if the previous value put into `Storage` has not been consumed, in order not to delay the housekeeping function. In this case, the stored value is overwritten. Notice that this differs from the classical specification of a bounded buffer.

The `OBSW` main procedure initialises the board LEDs and the `Housekeeping` and `TTC` subsystems toggle blue and orange LEDs. The activity of both subsystems is carried out by their respective tasks, which start executing concurrently with the main task. The initialization procedures return to the main procedure, which enters an endless loop doing nothing and running in parallel with the other tasks. In order not to disturb the execution of the subsystems tasks, the main loop runs at the lower possible priority, which is specified in the `obsw.ads file.`

4.2 Compile and run with the debugger.

Open GPS and do the following:

1. Select `Open project` on the welcome window. Navigate to the LAB4 directory and open the `tasking_housekeeping.gpr` project file.

2. Build the executable and load it into the board by clicking on the  symbol in the tool bar (or select `Build` → `Bareboard` → `Debug` on board on the top menu).

   The program will be compiled, and the executable will be loaded into the board memory by the debugger. After that, the debugger is started, and the debugger console (lowest window in GPS) shows the following lines:

   ```
   ...
   (gdb) monitor reset halt
   (gdb)
   ```

3. Type `continue` or just `c` on the debugger console (or select `Debug` → `Continue` on the top menu).

   ```
   (gdb) c
   Continuing.
   [program running]
   ```

4. The program will start running (check the LED blinking), and the raw temperature readings are shown on the `Messages` tab of the debugger console as in the previous project.

4.3 Make changes to the program

It is advised that you make changes to the provided program in order to make sure that you understand the project implementation, and the mapping from the architecture to source code.

The proposed change is to: Include the conversion to Celsius in the `TTC.Send` procedure. The temperature transfer function is implemented by `HK_data-converter` which can be found in utilities.

Assignment 5

Distributed housekeeping program

The two previous versions of the housekeeping program display the measured values on a debugger console. This means that the program must be run from the debugger, with the ST-LINK cable in place.

A more realistic solution uses a serial interface to send these values to a simulated ground station running on the host computer, as shown in figure 2). The aim is to simulate the radio link between the satellite and the ground station.

5.1 Serial line connections.

This scheme makes use of the USB/UART interface cable provided to the students. The USB/UART cable has a TTL connector that must be connected to the STM32f4 board pins that convey the serial line (UART) signals (figure 5.1).

Figure 5.1: UART cable connector.

The connections to be made are summarized in the following table (see figure 3 for the location of the pins on the board):

Connector pin	Board pin
1 (black)	GND
4 (orange)	PB7
5 (yellow)	PB6

Table 5.1: Serial line connections on board.

The other end of the interface cable has a USB-A connector that must be plugged to a USB port on the host computer. The values sent to the host computer are displayed using a terminal application that can handle a USB serial port. The host terminal application should be set to taking the USB serial port as input with a transmission rate of 115200 bps and 8N1.

5.2 Host terminal application.

5.2.1 Windows

The recommended application to display messages received on the USB serial port is PuTTY. You can download an installation package from `https://www.putty.org`.

In order to configure the application, you need first to identify the COM port corresponding to the USB serial line. Open the Device Manager and look at the USB Serial Port entry. The COM port is displayed next to it (e.g. COM 4 in figure 5.2).

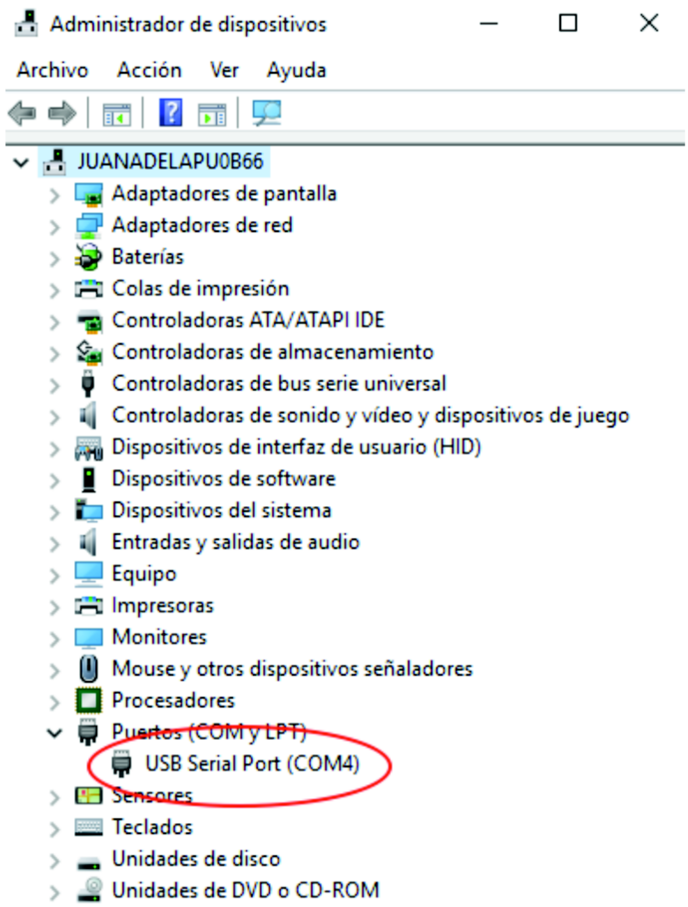


Figure 5.2: Identification of usb serial port.

Now, to set up PuTTY, open the application and set the configuration parameters as shown in figure 5.1.

5.2.2 MacOS

The recommended application is screen, which is already installed in MacOS. First you have to identify the USB serial port. Open a terminal window and type

```
$ ls /dev | grep -i usb
```

You will get a list of devices like the following:

```
cu.usbserial-FTA5I24G
tty.usbserial-FTA5I24G
```

As you can see, there are two devices for each serial line. You can use any of them, but for reasons not to be discussed here it is better, in general, to use the one starting with cu.

To use the screen application enter the following command:

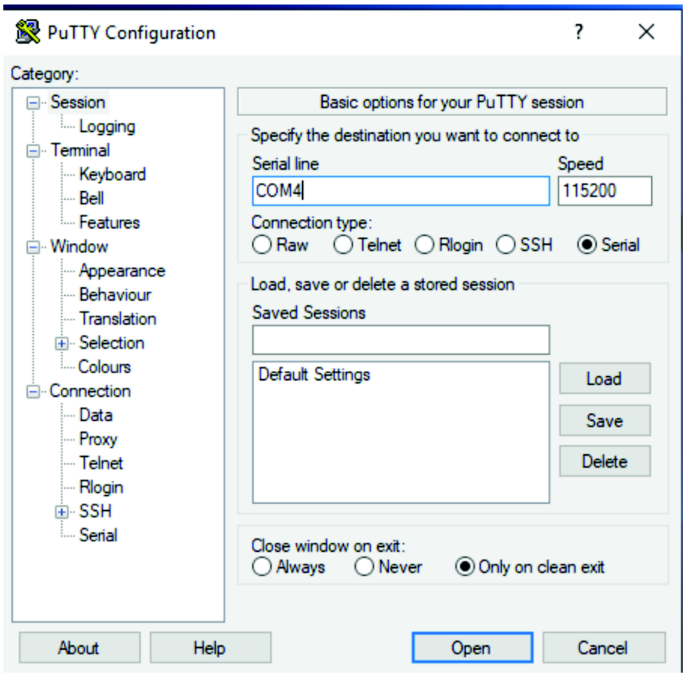


Figure 5.3: PuTTY configuration.

```
$ screen /dev/cu.usbserial-XXXX 115200
```

where `/dev/cu.usbserial-XXXX` is the name of your device.

To exit the application, type CTRL-A and then CTRL-K.

5.2.3 GNU Linux

The recommended application is screen[1], which can be installed in Ubuntu Linux with:

```
$ sudo apt install screen
```

In order to identify the USB serial port, type the following command on a terminal:

```
$ ls /dev | grep -i usb
```

You will get a result like the following:

```
ttyUSB0
```

To use the screen application enter the following command:

```
$ screen /dev/ttyUSB0 115200
```

To exit the application, type CTRL-A and then SHIFT-K.

5.3 Software architecture

The software architecture is similar to the previous project, except that the display is replaced by a serial line handler adapted from the examples in the Ada Drivers Library.

5.3.1 Download the code and study the implementation

The implementation code, as initially provided to the students, can be downloaded from `https://github.com/STR-UPM/OBDH_LABS`. Click on `Clone` or `download`, download a zip archive, unzip and move to your work directory. The code for this assignment is in the LAB5 folder.

[1] `gtkterm` or `kermit` are good alternatives

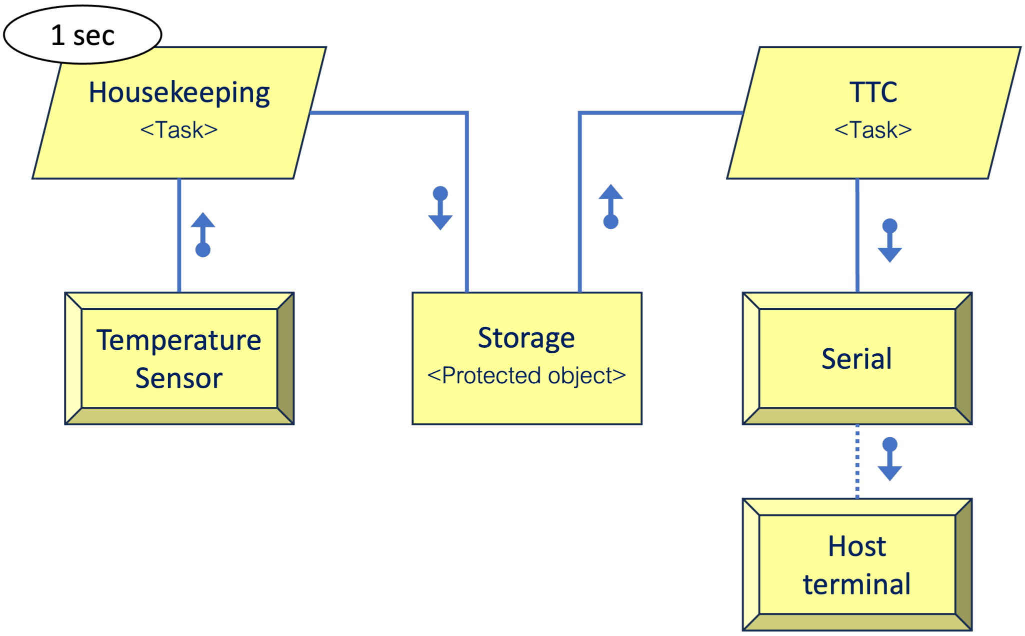


Figure 5.4: Software architecture of the distributed housekeeping system.

The `Serial` component is implemented by the `Serial.IO` package and other packages in the `serial_ports` folder. These packages have been adapted from the examples in the Ada Drivers Library. The blocking kind of serial port has been chosen for this project. This means that the task calling the `Put` operation (`TM_Task`) waits on a busy loop until the operation is complete.

The rest of the implementation is the same as in the previous project.

5.4 Compile and run.

Open GPS and do the following:

1. Select `Open` project on the welcome window. Navigate to the LAB5 directory and open the `distributed_housekeeping.gpr` project file.
2. Build the executable and load it into the board by clicking on the symbol in the tool bar (or select `Build` → `Bareboard` → `Flash to board` on the top menu).

   The program will be compiled, and the executable will be loaded into the board flash memory. After that, the program starts to run on the board (check the blinking LEDs).
3. Connect the serial cable to a USB port on the host computer, if not already done.
4. Identify the serial port name on the host computer and launch the remote terminal application as explained in section 5.2. The sensor measured values will start being displayed on the host application.

5.5 Make changes to the program

You may include the same changes that were proposed in the previous assignment:

1. Include the conversion to Celsius in the `Display.Put` procedure.

Assignment 6

Real-time program

The next version of the housekeeping program includes real-time requirements and the use of a real-time clock to add a timestamp to the housekeeping data sent to the ground station, simulated by the serial connection to the host PC like in the previous assignment. The hardware connections and the use of a host terminal application remain the same.

6.1 Software architecture

The software architecture now includes a period of 10 s for the `TTC` task. This task reads the last value from the storage every 10 seconds (figure 6.1).

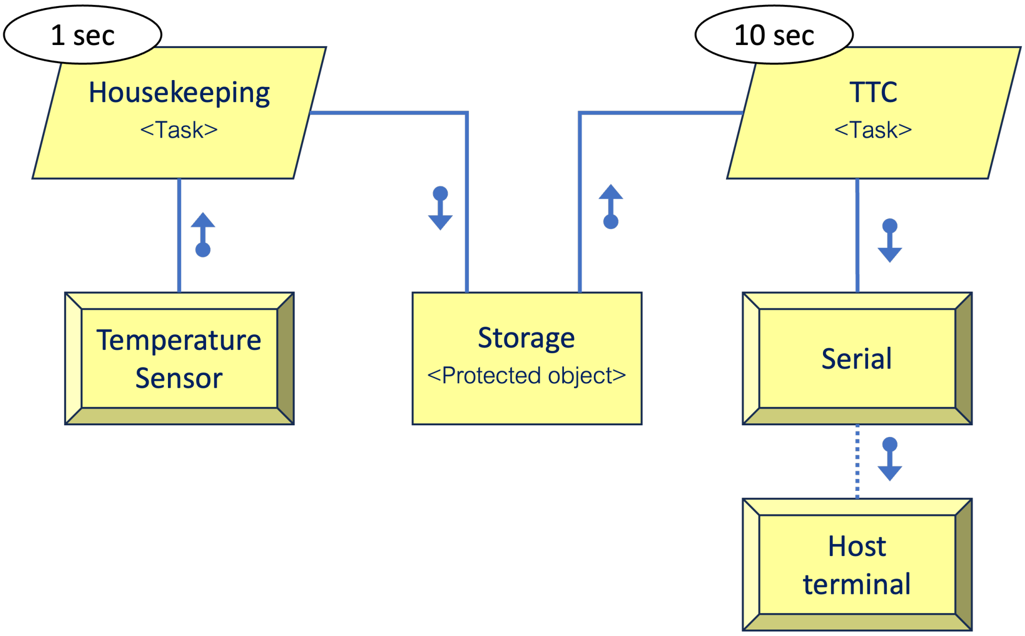


Figure 6.1: Software architecture of real-time housekeeping system. The only difference with the previous assignment is the 10 sec period of the `TTC` task.

6.2 Real-time requirements

The following real-time requirements are specified for the system:

- The `Housekeeping` task executes with a period of 1 s and has a deadline equal to its period, (1 s).
- The `TTC` task executes with a period of 10 s and has a deadline of 2 s.

Priorities are assigned in deadline-monotonic order, as shown in table 6.1. The Buffer protected object, which is part of the `Storage` implementation, is accessed by both application tasks and thus has a ceiling priority equal to the priority of the `Housekeeping` task.

Task	Period	Deadline	Priority
Housekeeping	1.0	1.0	20
TTC	10.0	2.0	10
Storage buffer	-	-	20

Table 6.1: Real-time requirements.

6.3 Download the code and study the implementation.

The implementation code, as initially provided to the students, can be downloaded from `https://github.com/STR-UPM/OBDH_LABS`. Click on `Clone` or `download`, download a zip archive, unzip and move to your work directory. The code for this assignment is in the LAB6 folder.

The implementation code differs from the previous project in several aspects.

- Period and priority values have been explicitly added to the specification of the `Housekeeping` and `TTC` packages. A start delay has been added to the respective tasks, in order to let all the packages initialize before the regular operation of the system starts.
- The ceiling priority of the `Storage` buffer has been set to the same value as the `Housekeeping` task.
- A new `State` data type has been defined, which is a record including a timestamp and an analog data value. Messages sent to ground are now of this data type.

  Timestamps are refined as 64-bit integers, denoting the number of second elapsed since the beginning of the mission. To the purpose of this laboratory this value is taken from the real-time clock provided by the `Ada.Real_Time` library package.
- In order to improve the visual aspect of the messages as viewed on the host terminal application, a new package, `Data_Images`, has been added that provides fixed-width string images of mission time and analog data values. i

The rest of the implementation is the same as in the previous project.

6.4 Compile and run.

Open GPS and do the following:

1. Select `Open` project on the welcome window. Navigate to the LAB6 directory and open the `realtime_housekeeping.gpr` project file.
2. Build the executable and load it into the board by clicking on the  symbol in the tool bar (or select `Build` → `Bareboard` → `Flash to board` on the top menu).

   The program will be compiled, and the executable will be loaded into the board flash memory. After that, the program starts to run on the board (check the blinking LEDs).
3. Connect the serial cable to a USB port on the host computer, if not already done.
4. Identify the serial port name on the host computer and launch the remote terminal application as explained in section 5.2. The sensor measured values together with their respective timestamps will start being displayed on the host application (figure 6.2).

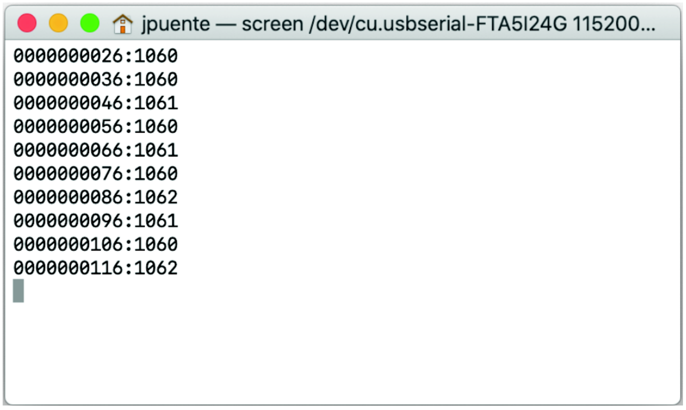


Figure 6.2: Sample output on host terminal.

6.5 Perform a temporal analysis of the system.

In order to carry out a response-time analysis of the temporal behaviour of the system, you will need to measure the execution time of the task bodies and the protected procedure bodies. A simple loop technique using the standard real-time clock will be enough for this assignment.

An execution time measurement tool is available in the LAB6 directory. In order to use it, perform the following steps:

1. Open GPS and select `Open` project on the welcome window. Navigate to the LAB6 directory and open the `wcet_meter.gpr` project file.
2. Build the executable and load into the board in the same way as for the realtime_housekeeping.gpr project.
3. Make sure that the serial cable is still connected to the board and the USB port in the host computer. If the remote terminal application is not open, open it.

A measurement test is executed on the board, and repeated every 60 s. The output of the test is shown on the host terminal application (figure 6.3). The output shows the execution times for the bodies of the `Housekeeping` (HK) and `TTC` (TC) tasks, as well as the bodies of the protected operations of the `Storage` object (ST). Notice that a new entry, `Get_Immediate`, has been added for the latter in order *to avoid the measuring task to get blocked*. The new entry is exactly the same as `Get` but has a `True` barrier so that it is always open.

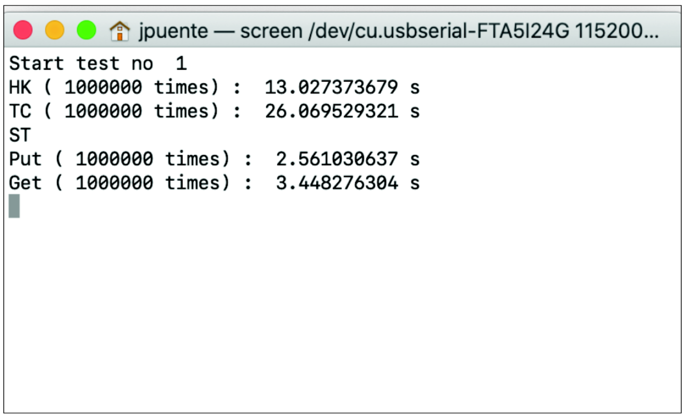


Figure 6.3: Output of wcet measurement tool.

In the example shown on figure 6.3, the HK execution time has been measured 10^6 times, with a total measurement time of 13.02 s. Therefore, the value to be taken for the response time analysis is $13.02 \cdot 10^{-6}$ s $= 13.02$ μs, and the same for the other tasks. Take into account that the values measured on your board will probably be slightly different from the above shown.

Once you have an estimate of worst case execution times, apply the RTA equations for computing the worst-case response time and check if all the deadlines are met. The setup for the calculations is shown on table 6.2 containing the period (T), execution time (C), blocking time (B), deadline (D), response time (R), and priority (P) of all tasks. The last two columns (Storage and Operation) present the protected object called `Storage` that is accessed with a mean execution time of $3 \cdot 10^{-6}$ seconds by the `Housekeeping` task through its CPut operation, and $4 \cdot 10^{-6}$ seconds by the `TTC` task through its CGet operation. Finally, the last row contains the ceiling priority of the Storage protected object.

Task	T	C	B	D	R	P	Storage	Operation
Housekeeping	1.0	$13 \cdot 10^{-6}$	?	1.0	?	20	$3 \cdot 10^{-6}$	CPut
TTC	10.0	$26 \cdot 10^{-6}$	?	2.0	?	10	$4 \cdot 10^{-6}$	CGet
						Ceiling Priority	?	

Table 6.2: Data arrangement for RTA of the housekeeping system. Time units in seconds.

Assignment 7

Real-time program with Attitude Control System

The aim of this assignment is to validate the Attitude Control System (ACS) with the Processor In the Loop (PIL) technique. PIL consists on the simulation from the external environment through mathematical models (designed in Simulink) that are directly connected to the onboard computer. This way, we can analyze the system's behaviour based on simulated readings and actuations performed by the OBSW.

The real-time version of the On-Board Software (OBSW) is used with the ACS of the UPMSat-2 satellite. The ACS uses magnetic sensors and actuators, which is commonly known as magnetic attitude control (figure 7.1).

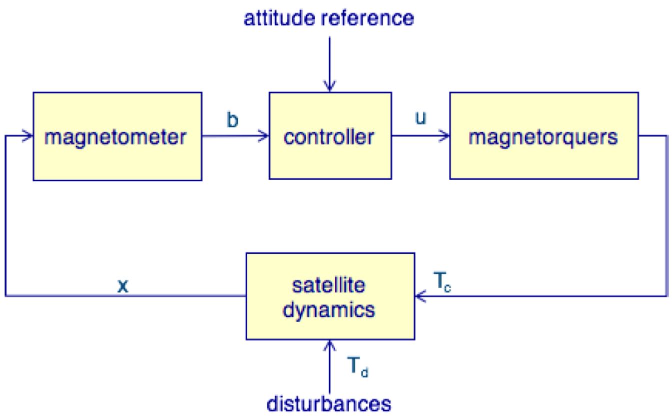


Figure 7.1: Magnetic attitude control system.

Magnetometers are magnetic sensors that provide a measurement of the strength and direction of the magnetic field, i.e. the magnetic field vector, at a given point. **Magnetorquers** are magnetic coil which produce a magnetic moment that interacts with the Earth's field, thus enabling the attitude of the satellite to be changed.

7.1 Model In the Loop (MIL) validation

Software validation usually includes testing the system under real operating conditions. However, for obvious reasons, on-board space software as well as many other embedded systems cannot be tested in this way. Simulation models are commonly used in these cases.

The first validation phase uses a model of the ACS, together with models of the space environment and the spacecraft dynamics, to assess the validity of the control law and the design parameters (figure 7.2). This is usually carried out by a control engineer using a simulation tool. Simulink is commonly used for ACS development.

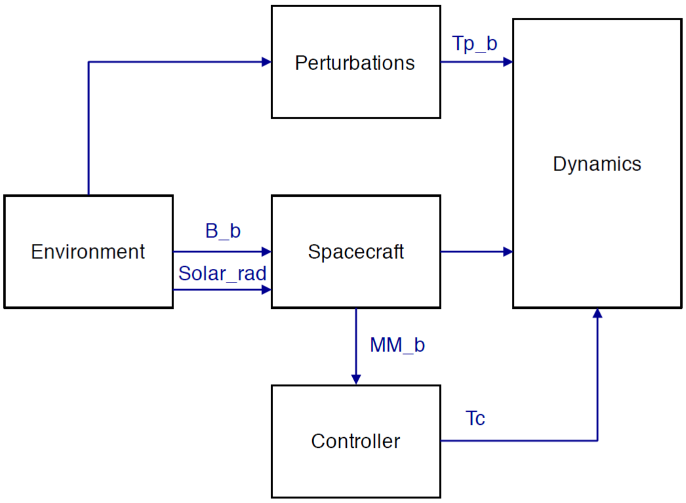


Figure 7.2: UPMSat-2 ACS high level model view.

The ACS simulink model can be simulated by running **matlab** from directory LAB7/ACS and opening ACS.slx. Three new windows will be pop-up: the simulink window with the ACS model and two scope windows that show the angular velocity of the satellite in body reference and the actuation over the three magnetorquers.

The Simulink window (figure 7.3) shows the high level blocks: the satellite's model is located in the middle (turquoise block), its dynamics and the models of the Earth's field and Sun with the perturbations.

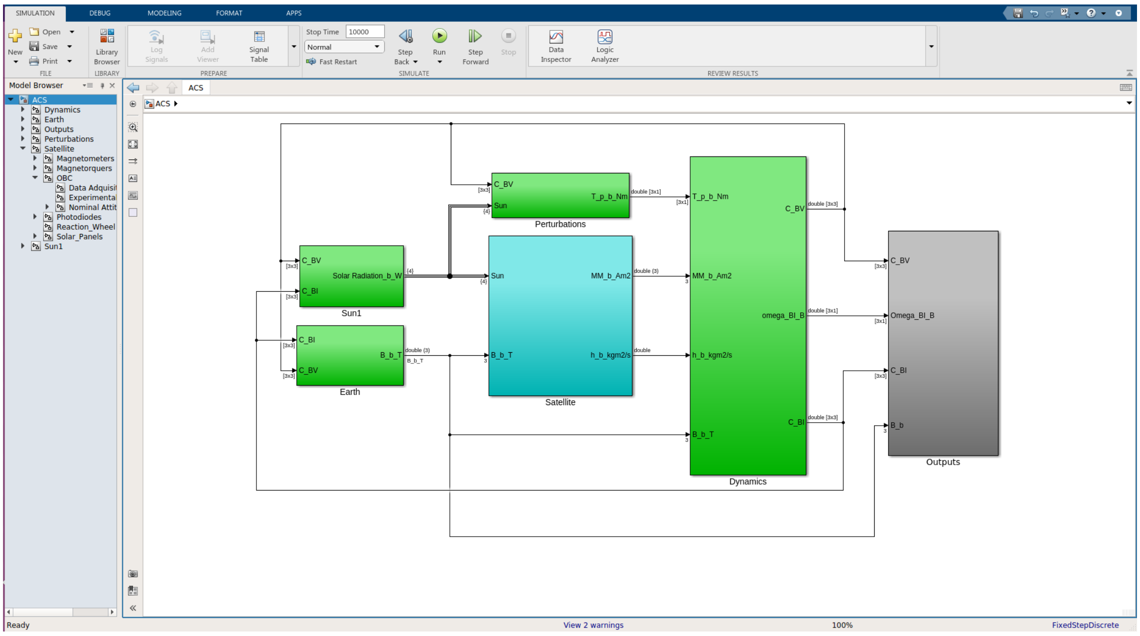


Figure 7.3: UPMSat-2 simulink model.

The nominal attitude control can be visualized by selecting `Nominal Attitude Control` in the Model Browser menu (left part of simulink window) or by clicking on `Satellite` → `OBC` → `Nominal Attitude Control` blocks.

Nominal attitude control has three blocks (figure 7.4):

Sensor samples the analog inputs of the magnetometers. The inputs are converted to engineering units using calibration data.

Control implements the attitude control law that computes the control action to be output to the magnetorquers.

Actuator activates the magnetorquers according to the computed control action.

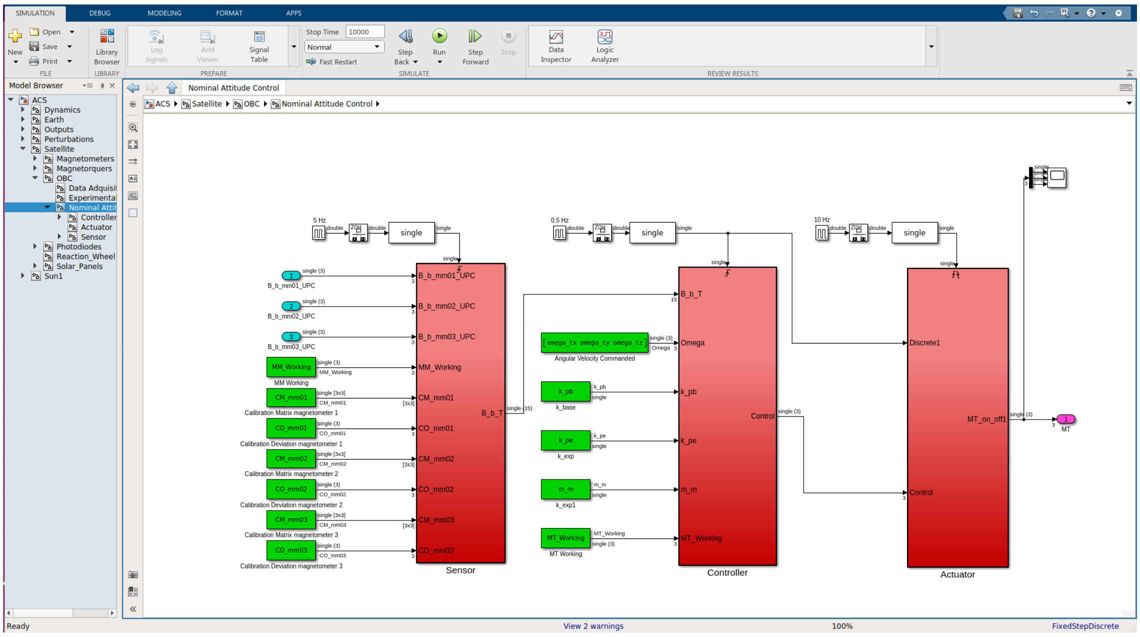


Figure 7.4: Nominal attitude control.

To simulate the model an verify its behaviour, click on Run bottom. The evolution of the angular velocity of the satellite and the actuation over the three magnetorquers will be shown in the corresponding scope windows. The commanded angular velocity set-point is [0, 0, 0.1] rad/s and the result of the simulation (figure 7.5) shows the evolution from the initial angular velocity ([0.1, -0.1, -0.1] rad/s).

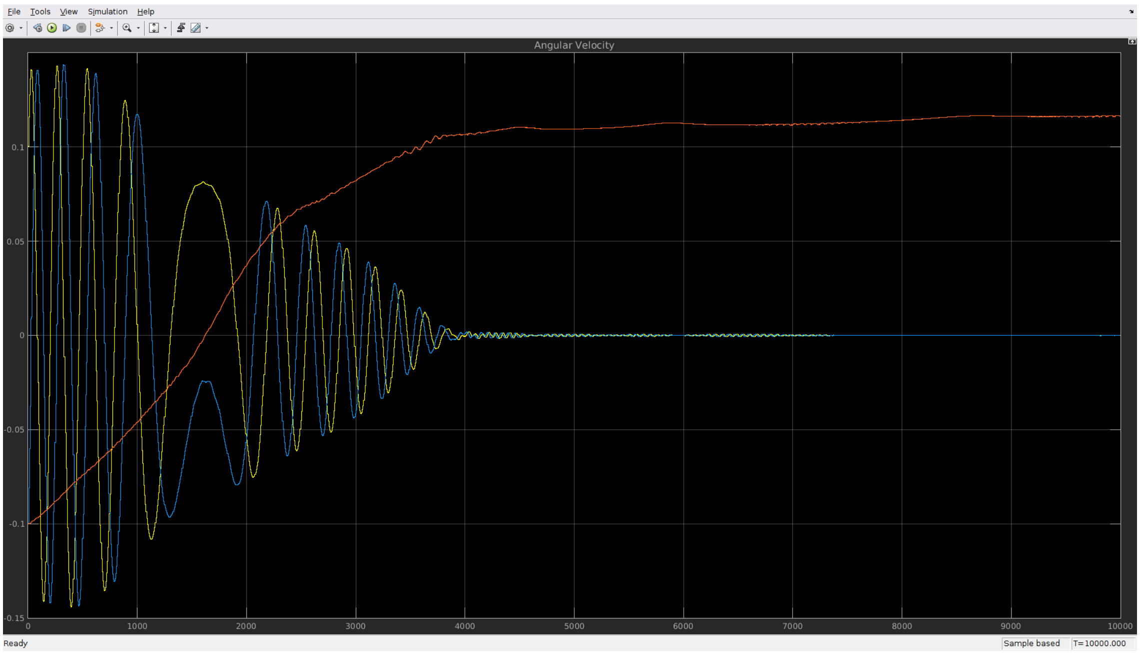


Figure 7.5: Angular velocity evolution.

7.2 Code generation.

The next step is execute the ADCS on hardware. In this assignment, only the Control block will be execute on the target board. The corresponding code can be generated by using the Embedded Coder toolbox but it is needed to isolate Control block from the ACS model. It can be done by clicking in the Control block, selecting all the block content (except the trigger block) and saving it in a new model.

This model named control.slx can be found in LAB7/ACS_PIL directory. Use `matlab` to open it and then select `APPS` in the top menu, `Embedded Coder` will appear. If not, it must be installed by clicking `Get Add-Ons` and searching it. The Embedded Coder window (figure 7.6) will appear after clicking on Embedded Coder icon.

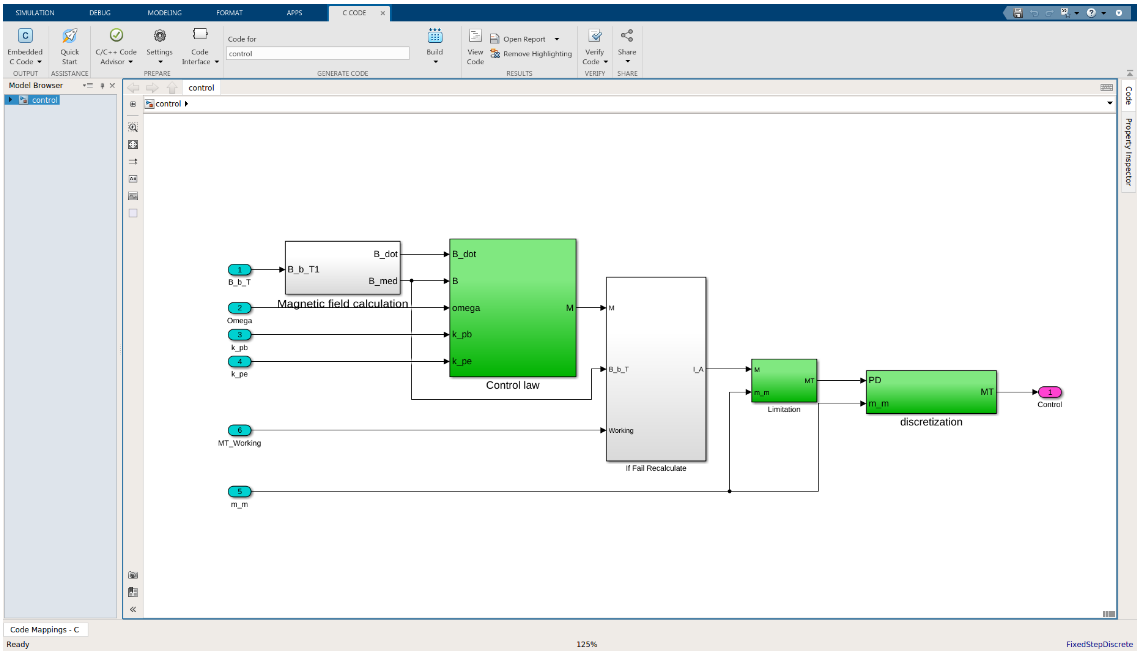


Figure 7.6: Embedded Coder toolbox.

The code generation option as well as characteristics of the target hardware can be set by clicking on the `Settings` menu. The `control.slx` model has already the proper options, therefore you can take a look but be carefully and do not modify then.

Now the code can be generated by clicking on the `Build` menu. Once upon the code is generated, a code generation report window appear. It is possible to explore the generated code together with different code metrics. Click on `control.h` and look for lines 50-79 (figure 7.7) where the generated code interface is located.

There are two record type definitions (`struct`) called `ExternalInputs` and `ExternalOutputs` that are used to interchange data with the blocks `Sensor` and `Actuator` (figure 7.4). Data are interchanged with two objects of these record types: `rtU` and `rtY`. There are also two functions: function `control_initialize` initializes the control code and function `control_step` performs the control algorithm.

The generated code will be embedded in the real-time program by taking into account this interface.

7.3 Software architecture

The implementation code, as initially provided to the students, can be downloaded from `https://github.com/STR-UPM/OBDH_LABS/LAB7`.

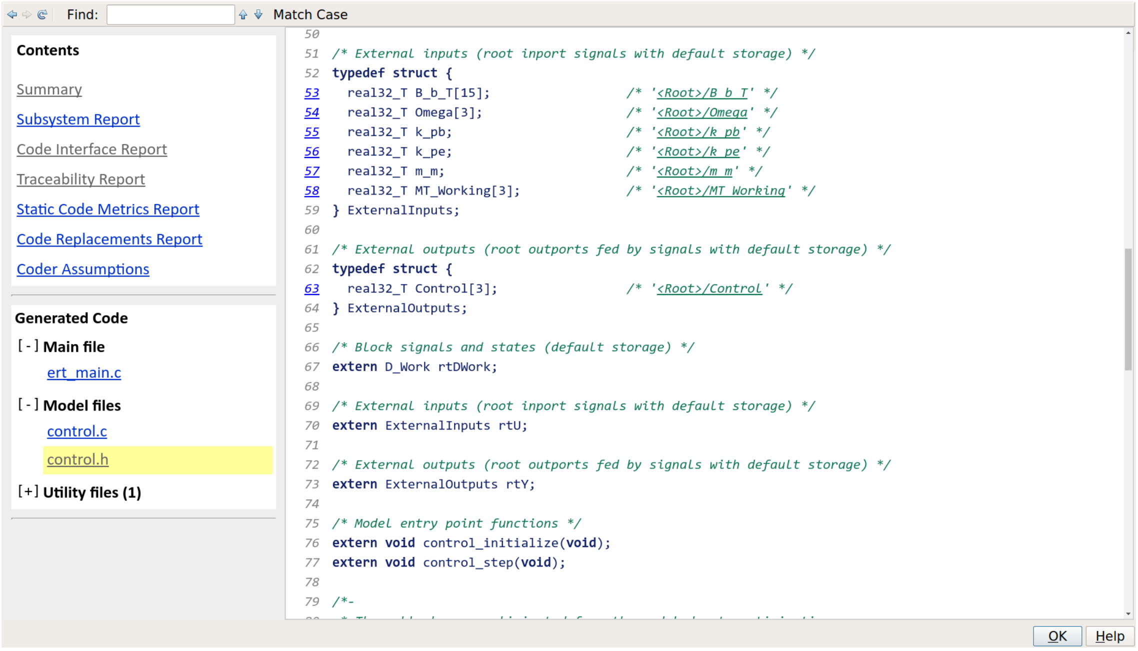


Figure 7.7: Code generation report.

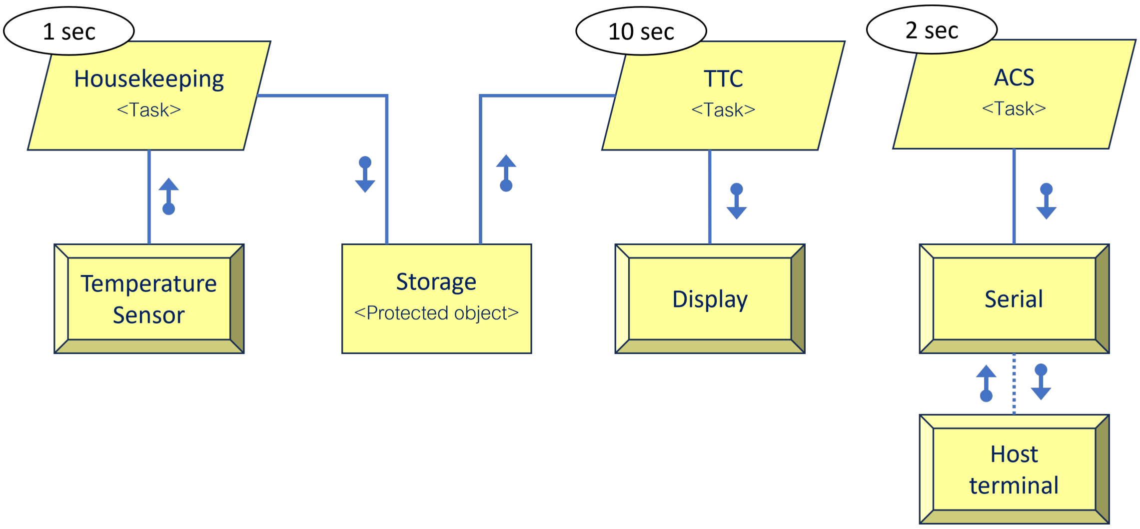


Figure 7.8: Software architecture of the real-time program with ACS.

The software architecture of the the real-time program with ACS is depicted in figure 7.8 and the differences with the previous architecture (figure 6.1) are:

The `ADCS` package is the root element of the ADCS. Its specification consists of one procedure, `Initialize`, that starts the operation of the component. It has three subpackages:

ADCS is the root package of the subsystem and contains a concurrent task, `ADCS_Task` that reads the magnetic field vector from `Sensor`, calculates the actuation vector and sends it to `Actuator` (see figure 7.4). It also toggles the red LED every two second.

The body of this package uses the generated code by setting the inputs, calling the functions and retrieving the outputs following the interface of figure 7.7. `ADCS_Task` performs the control algorithm by calling `control_step`. This is shown in figure 7.9. It uses `Export` and `Import` pragmas to interface the generated C code.

```
package body ADCS is

   -- controller block input and ouput objects must be global
   Control_Input : Controller_Input;
   pragma Export (C, Control_Input, "rtU");

   Control_Output : Controller_Output;
   pragma Export (C, Control_Output, "rtY");

   --  Initialize the ADCS subsystem
   procedure Initialize is
      procedure Control_Initialize;
      pragma Import (C, Control_Initialize, "control_initialize");
   begin
      Control_Initialize;
   end Initialize;

   -- ADCS task
   task body ADCS_Task is
      procedure Control;
      pragma Import (C, Control, "control_step");
      Next_Time   : Ada.Real_Time.Time := Ada.Real_Time.Clock + Initial_Delay;
   begin
      loop
         delay until Next_Time;
         Control_Input.B_b_T := ADCS.HW.Get;
         Control;
         ADCS.HW.Put (Control_Output.Control);
         STM32.Board.Red_LED.Toggle;
         Next_Time := Next_Time + Period;
      end loop;
   end ADCS_Task;
end ADCS;
```

Figure 7.9: Implementation of ACS package.

ADCS.Parameters contains the definitions of the data types used in the subsystem and parameters that are used to tune the control algorithm. These parameters can be changed by telecommand in the UPMSat-2 OBSW. The data type `Controller_Input` is used to read the magnetic field vector in teslas, which are IEEE single precision float numbers. The data type `Controller_Output` are used to send the actuation to magnetorquers in seconds[1], which are IEEE single precision float numbers. These data types correspond to the generated C structs `ExternalInputs` and `ExternalOutputs` (see figure 7.7).

ADCS.HW is in charge of getting the magnetic field vector and putting the actuations. It hides the details of the hardware. Its specification includes the `Put` and `Get` subprograms. This package uses the serial port to interchange magnetic field and actuation values with the Software Validation Facility.

The Software Validation Facility (SVF) is an auxiliary computer, linked to the OBC by a serial line, to run a simulation model of the Earth's magnetic field and satellite dynamics. In this way, engineering values can be interchanged. Host computers are also used as SVF by executing a Simulink™model of the Earth's magnetic field and satellite dynamics.

In this assignment, the serial line is used to interchange data between ADCS and SVF. Therefore, housekeeping telemetry are send to a text console that is simulated on the host computer using semihosting as in assignments 3 and 4.

[1]In UPMSat-2 ACS, Pulse Width Modulation (PWM) is used. Therefore outputs are the duration of actuations (duty cycles) on magnetorquers and resulting units are joule-seconds.

7.4 Compile and run with the debugger.

Open GPS and do the following:

1. Select `Open project` on the welcome window. Navigate to the LAB7 directory and open the `realtime_housekeeping.gpr` project file.

2. Build the executable and load it into the board using the debugger by clicking on the  symbol in the tool bar (or select `Build` → `Bareboard` → `Debug` on board on the top menu).

   The program will be compiled, and the executable will be loaded into the board memory by the debugger. The debugger console (lowest window in GPS) shows the following lines:

   ```
   ...
   (gdb) monitor reset halt
   (gdb)
   ```

3. Type `continue` or just `c` on the debugger console (or select `Debug` → `Continue` on the top menu).

   ```
   (gdb) c
   Continuing.
   [program running]
   ```

   After that, the program starts to run on the board and temperature reads are displayed on messages tab of the debugger window. However, the red LED does not blink because `ACS` is waiting sensor inputs from SVF.

7.5 Processor In the Loop (PIL) validation.

The SVF shall provide sensor inputs and retrieve magnetotorquer outputs. To do that, the remain part of the original simulink model will be used, i.e. all the blocks except the Sensor block.

This model named `ACS_PIL.slx` can be found in LAB7/ACS_PIL directory. Open it and again three new windows will be pop-up: the simulink window with the ACS_PIL model and two scope windows that show the angular velocity of the satellite in body reference and the actuation over the three magnetorquers.

The Control block of this model has been substituted by serial link connections as shown in figure 7.10. Identify the serial port name on the host computer and edit the serial configuration block by selecting the serial line of your PC.

Additional rate transition blocks has been added for a proper communication and a `Real-Time Pacer` block has been also added to set the simulation speed[2].

Start the simulation and verify angular velocity stabilization. Now ADC runs and red LED is toggled.

7.6 Make changes to the simulation.

- Default parameters for control blocks can be changed in Ada source file `ACS-parameters.ads`.
  - `Default_omega` is the consigned angular velocity.
  - `Default_MT_Working` contains the operational magneto-torques.

  In UPMSat-2 many parameters can be changed by TC.

- The initial angular velocity can be changed in Simulink source file `initialization.m`.
  - `omega_BI_B0 = [0.1;-0.1;-0.1];`

[2]In a real case, an speedup equal to 1 should be used but it is to slow.

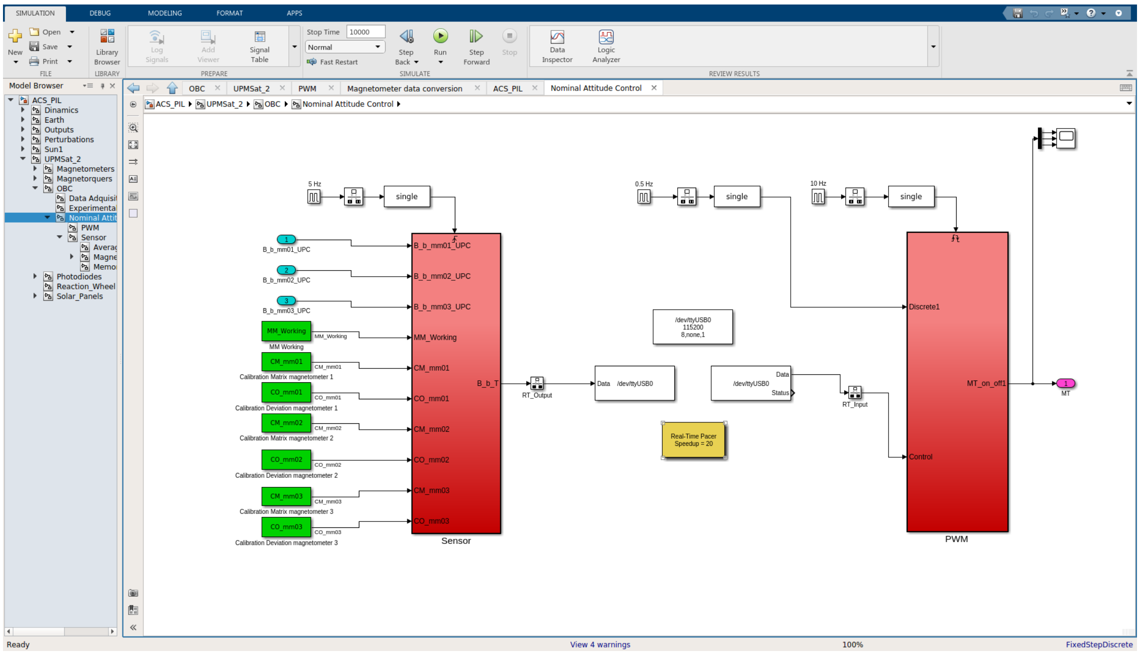


Figure 7.10: Nominal attitude control for PIL.

Final project

OBDH system

The final version of the housekeeping program is a full OBDH system, including an additional sensor readings and the reception and interpretation of elementary telecommands from the ground station.

The ground station is implemented by a separate program running on the host PC platform. The radio connection between the OBDH software running on the OBC board and the ground station running on the host PC is simulated by a serial cable connection, as in assignments 5 and 6.

8.1 Software architecture and functional overview

The software architecture is shown on figure 8.1. The system consists of four subsystems, very much like the ones found in a real on-board satellite system.

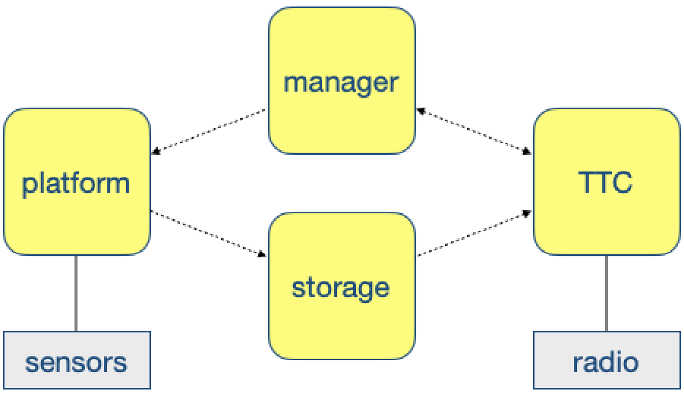


Figure 8.1: OBDH system architecture.

- The `platform` subsystem performs housekeeping functions on the satellite platform. It is expanded from the housekeeping component developed in the previous laboratory assignments in order to include an additional sensor. The list of variables that are monitored is now:
  - OBC_T : OBC temperature
  - OBC_V : OBC voltage

  The state of the platform is the set of values measured at a particular time, with a timestamp indicating the time at which they have been acquired. Mission time, a monotonic seconds count from the system start time, is used to this purpose.
- The `storage` subsystem keeps trace of the last N state values measured by the platform subsystem, where N is a configurable system parameter.
- The `TTC` system is in charge of all communications with the ground station. Its functionality includes:

- `Telemetry` (TM) messages transmitted to ground, which may be of the following kinds:
  * `Basic` telemetry (Hello) messages, including the last measured values from all the sensors. These messages are periodically transmitted when the system is in idle mode (see below).
  * `Housekeeping` messages include a more complete record with the last N stored values of the state. These messages are transmitted in response to a telecommand.
  * `Mode` messages indicating the current operating mode of the system are transmitted after every mode change (see below).
  * `Error` messages are occasionally sent to indicate some kinds of errors.
- `Telecommands` (TC) are messages received from ground, and can be of the following kinds:
  * `Open_Link` messages are sent from the ground station in order to start a coverage period (see below).
  * `Request_HK` telecommands are used to request the OBDH system to send a housekeeping telemetry message.
  * `Close_Link` telecommands are sent by the ground station in order to close a coverage period and return to the idle mode (see below).
  * An `error` TC value is signalled by the TTC subsystem when a message received from ground cannot be properly decoded as a valid TC.

- The `manager` subsystem carries out functions related to the operating mode of the system and the execution of telecommands. In this simplified OBDH system only two modes of operation are defined, related to the (simulated) visibility of the satellite from the ground station.
  - `Idle`. The system is this mode when the satellite is not visible from the ground station.
  - `Coverage`. The system is in coverage mode when the satellite is visible from the ground station.

  Mode changes are started from the TTC subsystem, according to the following protocol:

- When in `idle` mode, the OBDH system periodically transmits basic TM messages, and listens to telecommands from ground. When an open_link TC is received, it requests the manager to switch to the coverage mode. No other kinds of telecommands are accepted in this mode.
- When in `coverage` mode, basic telemetry is not transmitted, and the TTC subsystem listens to telecommands from the ground station. The system switches back to idle mode when a close link TC is received or, alternatively, a maximum coverage time span has passed.

8.2 System design

The task structure of the system that has been designed in order to provide the above functionality is shown on figure 8.2.

8.3 Real-time requirements

The following real-time requirements are specified for the system:

- The `Housekeeping` task executes with a period of 1 s and has a deadline of 100 ms.
- The `Basic_TM` task executes with a period of 10 s and has a deadline of 500 ms.
- The `TC` task is sporadic, and is executed upon reception of a telecommand. The minimum separation of the event is 2 s, and the deadline is 1 s.
- The `Coverage_Timer` task is sporadic with a minimum separation of 60 s and a deadline of 1 s.

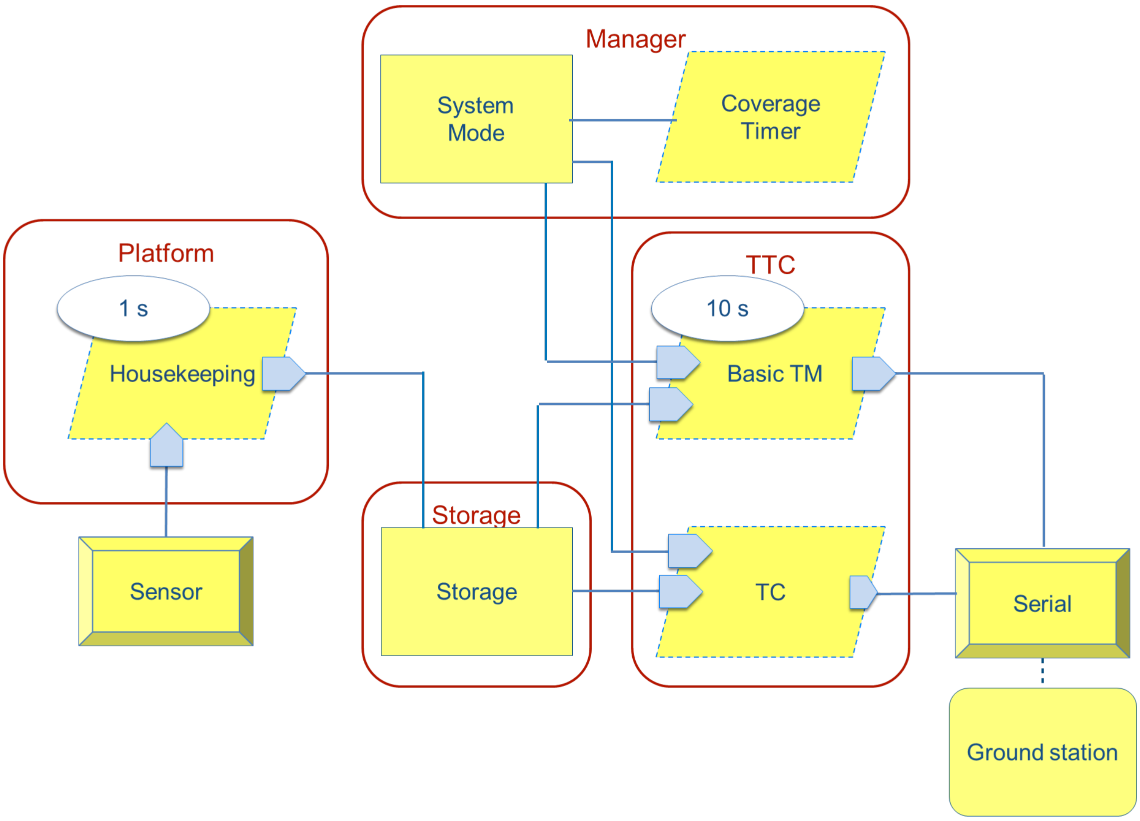


Figure 8.2: OBDH system task structure.

Priorities are assigned in deadline-monotonic order, as shown in table 8.1. The `Buffer` protected object, which is part of the `Storage` implementation, is accessed by the `Housekeeping`, `Basic_TM` and `TC` tasks, and thus has a ceiling priority equal to the priority of the `Housekeeping` task.

Task	Period	Deadline	Priority
Housekeeping	1.0	1.0	20
Coverage_Timer	60.0	1.0	15
Basic_TM	10.0	0.5	12
TC	1.0	1.0	10
Storage buffer	-	-	20

Table 8.1: OBDH real-time requirements.

8.4 Download the code and study the implementation

The implementation code, as initially provided to the students, can be downloaded from `https://github.com/STR-UPM/OBDH_LABS`. Click on `Clone` or `download`, download a zip archive, unzip and move to your work directory. The code for the OBDH system is in the PROJECT/OBDH folder.

The implementation code reflects the task structure in figure 8.2.

8.5 Compile and run.

Open GPS and do the following:

1. Select `Open` project on the welcome window. Navigate to the PROJECT/OBDH directory and open the `obdh.gpr` project file.

2. Build the executable and load it into the board by clicking on the symbol in the tool bar (or select `Build` → `Bareboard` → `Flash to board` on the top menu).

   The program will be compiled, and the executable will be loaded into the board flash memory. After that, the program starts to run on the board (check the blinking LEDs).

3. Connect the serial cable to a USB port on the host computer, if not already done, following the instructions in section 5.1 of this manual.

4. Identify the serial port name on the host computer and launch the remote terminal application as explained in section 5.2.The output shows all telemetry messages received from the board, including basic housekeeping in idle mode and responses to telecommands (figure 8.3).

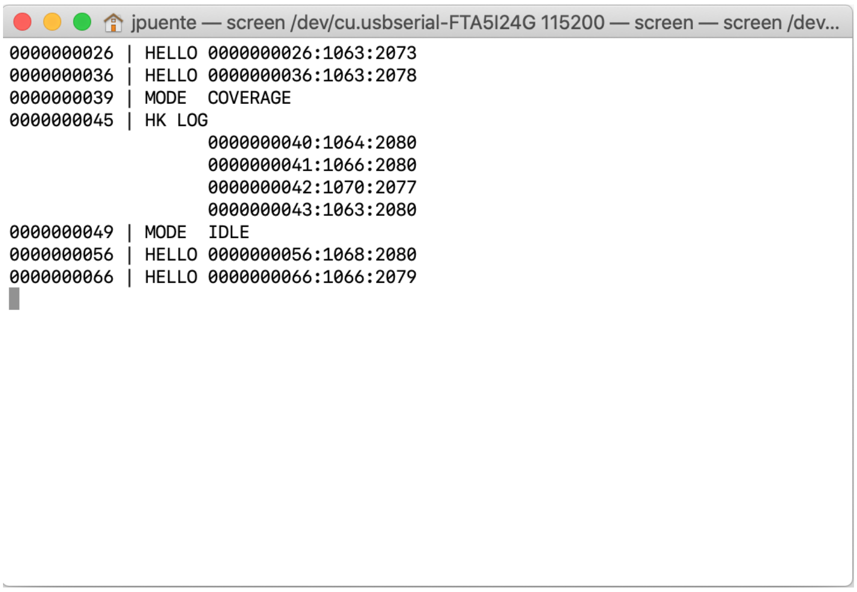


Figure 8.3: Sample telemetry messages received at the host terminal.

8.6 Ground station

The appearance of the output can be improved by using dedicated software. A simple example is the python script `gs.py` located in PROJECT/GS directory. In order to use it, do the following:

1. Install Python in your system, if not already installed.

2. Install the `pip` package manager if not already installed

3. Install the `pySerial` module:

   ```
   python -m pip install pyserial
   ```

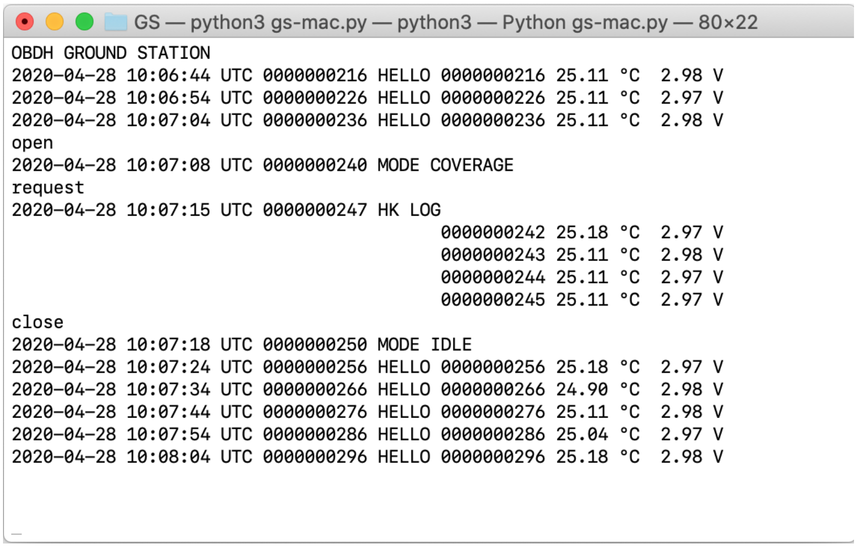
4. Edit the file `gs.py` and set the serial port name on the host computer :

   ```
   serial_port = 'COM4'
   ```

5. Run the script from a terminal window, with the board connected to the host PC:

   ```
   python gs.py
   ```

A sample of the telemetry messages received at the ground station is shown in figure 8.4. The command "exit" terminates the execution of the ground station script.



```
GS — python3 gs-mac.py — python3 — Python gs-mac.py — 80×22
OBDH GROUND STATION
2020-04-28 10:06:44 UTC 0000000216 HELLO 0000000216 25.11 °C  2.98 V
2020-04-28 10:06:54 UTC 0000000226 HELLO 0000000226 25.11 °C  2.97 V
2020-04-28 10:07:04 UTC 0000000236 HELLO 0000000236 25.11 °C  2.98 V
open
2020-04-28 10:07:08 UTC 0000000240 MODE COVERAGE
request
2020-04-28 10:07:15 UTC 0000000247 HK LOG
                                         0000000242 25.18 °C  2.97 V
                                         0000000243 25.11 °C  2.98 V
                                         0000000244 25.11 °C  2.97 V
                                         0000000245 25.11 °C  2.97 V
close
2020-04-28 10:07:18 UTC 0000000250 MODE IDLE
2020-04-28 10:07:24 UTC 0000000256 HELLO 0000000256 25.18 °C  2.97 V
2020-04-28 10:07:34 UTC 0000000266 HELLO 0000000266 24.90 °C  2.98 V
2020-04-28 10:07:44 UTC 0000000276 HELLO 0000000276 25.11 °C  2.98 V
2020-04-28 10:07:54 UTC 0000000286 HELLO 0000000286 25.04 °C  2.97 V
2020-04-28 10:08:04 UTC 0000000296 HELLO 0000000296 25.18 °C  2.98 V
```

Figure 8.4: Sample telemetry messages received at the GS script.

Written Assignment: Documented Report

Students have to write a brief report of about 2-4 pages on the work carried out during these sessions. The report should include:

- An analysis about cross-development environment for embedded systems and the main differences with a native environment.
- Optionally, the schedulabilty analysis proposed in section 6.5.
- The results from the ACS PIL simulation as shown in figure 7.5.
- The report can contain recommendations to improve the assignment and personal opinions.
- Optionally, if you have made the changes proposed in the assignments (or any other), you should include them in the report.

This report must be uploaded in a dedicated assignment from the Moodle platform.

Appendix A

Temperature sensor

The STM32F407 reference manual (section 13.10) states that the internal temperature sensor of the MCU is internally cabled to the ADC1_IN16 analog input channel. The steps required to read the sensor are:

1. Select ADC1_IN16 input channel in the ADC.
2. Select a sampling time greater than the minimum sampling time specified in the datasheet (see table A.1 below).
3. Set the TSVREFE bit in the ADC_CCR register to wake up the temperature sensor from power down mode.
4. Start the ADC conversion by setting the SWSTART bit (or by external trigger).
5. Read the resulting VSENSE data in the ADC data register.
6. Calculate the temperature using the following formula:

   Temperature (in °C) = (VSENSE - V25) / Avg_Slope + 25

   Where:

   - V25 = VSENSE value for 25 °C (table A.1)
   - Avg_Slope = average slope of the temperature vs. VSENSE curve (table A.1).

The sensor has a startup time after waking from power down mode before it can output VSENSE at the correct level. The ADC also has a startup time after power-on, so to minimize the delay, the ADON and TSVREFE bits should be set at the same time.

The sensor has a range of -40 to 125 °C, with a precision of ±1.5 °C. Its main characteristics are described in the STM32F407 datasheet (table A.1).

Symbol	Parameter	Min	Typ	Max	Unit
TL	VSENSE linearity with temperature	-	±1	±2	°C
Avg_Slope	Average slope	-	2.5		mV/°C
V25	Voltage at 25 °C	-	0.76		V
tSTART	Startup time	-	6	10	μs
TS_temp	ADC sampling time when reading the temperature (1 °C accuracy)	10	-	-	μs

Table A.1: STM32F407 temperature sensor characteristic.

The Ada Drivers Library includes the package STM32.ADC, which provides facilities for handling the analog to digital converter.