Embedded Systems Hands-On 1: Design and Implementation of Hardware/Software Systems

Task 4: Cortex-M0 Connected to External Components

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In this task, the Cortex-M0 will interface external components using three typical communication principles, i.e., digital asynchronous, digital synchronous, and analog interfaces. The task is scheduled for two weeks.

Summary

- Using the [ChibiOS] HAL
- UART communication between the Cortex-A53 and the Cortex-M0
- Sensor control via I^2C and ADC

In contrast to the last task, you are now encouraged to utilize all libraries provided by [ChibiOS]. These are provided with `ESH01/Materials/Environment` as version 20.3. The operating system modules (e.g., multi-threading, timing, memory management) are provided by [ChibiOS-RT], while [ChibiOS-HAL] abstracts the access to several peripherals (e.g., buses, ADCs, memories) for various microcontrollers. Many usage examples can be found in `Environment/ChibiOS/testhal`

1 Universal Asynchronous Receiver Transmitter

The UART communication protocol is often used in embedded systems. Also being error-prone, it is typically used for debugging purposes and other for low rate data transfers (e.g., to Bluetooth modules).

Summary

- Connect the Cortex-A53 to the Cortex-M0 via UART
- Test the correctness of the data transfer with a loop-back at 9600 baud, 19 200 baud, 57 600 baud and 115 200 baud.
- Plot error rate vs. transfer rate.
- What is the maximum achievable transfer rate for your setup?

A loop-back is used to test the UART connection between the Cortex-A53 and the Cortex-M0. Therefore, the latter has to echo each received symbol back to the sender. For the typical UART transfer rates (9600 baud, 19 200 baud, 57 600 baud and 115 200 baud), analyze the number of encountered transfer errors, i.e., the symbol received at the Cortex-A53 differs from the previously transmitted symbol. What might cause the transfer errors?

Minimum Expected Documentation

- The documented benchmark source code for both processors.
- Plotted and tabulated error rates.

2 Inter-Integrated Circuit

Embedded sensors are often controlled via I²C, as this bus requires only two signals for a synchronous bidirectional communication. The I²C peripherals are controlled by writing to dedicated registers. For the typical implementation, up top 128 devices can be connected to the same I²C bus. Lots of implementation details are not defined in the protocol standard, so the vendor specific sensor datasheets have to be taken into account.

Summary

- Abstract the register read and write access to the [LSM303D] in a separate class.
- Implement another class to simplify the acquisition of magnetometer and accelerometer samples. Convert these samples to SI units.
- Make the sensor data available via UART in a human readable format.

The [LSM303D] is integrated on a multi-sensor board (component U4 of the extension board). While the [ChibiOS] HAL provides a generic I²C driver, more knowledge from the datasheet is required to actually capture the sensed magnetic field (in $\mathrm{kg/A\,s^2}$) and acceleration (in $\mathrm{m/s^2}$). This knowledge should be encapsulated in separate classes. By making the samples available via UART, the Raspberry [Pi] can be used to capture longer time series of sensor data.

Minimum Expected Documentation

- The documented source code of the I²C sensor sampling program.
- Some exemplary UART transfers.

3 Analog to Digital Converter

Not all sensors provide a digital I^2C or SPI interface to gather the converted samples. Very simple (cheap) passive sensors and very accurate (expensive) sensors often expose their sensed information as an analog signal, either to make the component cheaper or to allow for application specific analog signal conditioning. In either case, an ADC is required to sample and digitize the analog signal. Fortunately, most microcontrollers provide an integrated ADC, whose resolution is sufficient to interface simple passive sensors.

Summary

- Abstract the ADC HAL to sample the [KPS-3227SP1C] light sensor in a separate class.
- Implement a calibration mechanism to adjust the minimum and maximum measurable illuminance in another class.
- Make the sensor data available via UART in a human readable format, i.e., percentage of the configured dynamic range.

The [KPS-3227SP1C] light sensor is integrated on the extension board and connected to one of the Cortex-M0 ADC input channels. The [ChibiOS] HAL provides a generic ADC driver, which can be used to implement a light sensor driver. Interpreting the voltage sampled by the ADC as illuminance would be possible, as the sensor datasheet specifies the illuminance vs. photo current behavior, and the extension board datasheet specifies the capacitor used to convert this current into the ADC input voltage. However, both information are not very accurate, so we simplify the voltage interpretation by a linear interpolation between (and saturation at) two extreme illuminance conditions. A mechanism to specify and apply these boundary conditions *at runtime* has to be implemented in a separate class. By making the samples available via UART, the Raspberry [Pi] can be used to capture longer time series of sensor data.

Minimum Expected Documentation

- The documented source code of the ADC sensor sampling program.
- Some exemplary UART transfers.

Bibliography

ChibiOS *Free embedded RTOS*. URL: `http://www.chibios.org` (visited on 2018-03-08).

ChibiOS-HAL *ChibiOS/HAL Introduction*. URL: `http://chibios.sourceforge.net/docs3/hal` (visited on 2018-03-08).

ChibiOS-RT *ChibiOS/RT Introduction*. URL: `http://chibios.sourceforge.net/docs3/rt` (visited on 2018-03-08).

KPS-3227SP1C Kingbright. *AMBIENT LIGHT PHOTO SENSOR*. 2010. URL: `http://www.farnell.com/datasheets/1776585.pdf` (visited on 2018-03-08).

LSM303D ST. *Ultra-compact high-performance eCompass: 3D accelerometer and 3D magnetometer module*. 2013. URL: `http://www.st.com/resource/en/datasheet/lsm303d.pdf` (visited on 2018-03-08).

Pi Raspberry Pi Foundation. *Raspberry Pi 3 Model B*. URL: `https://www.raspberrypi.org/products/raspberry-pi-3-model-b` (visited on 2018-03-08).

Acronyms

ADC Analog to Digital Converter
HAL Hardware Abstraction Layer
I²C Inter-Integrated Circuit
RTOS Real-Time Operating System
SI International System of Units
SPI Serial Peripheral Interface
UART Universal Asynchronous Receiver Transmitter