

TTK4147 - Real-time Systems

Exercise 4 - AVR32 UC3

September 2020

Remember to check in at the lab, <https://innsida.ntnu.no/checkin/room/3066>, to allow for easier infection control in the event of a Covid-19 infection on campus.

We will take a break from programming in Linux for now, and instead use the AVR32 UC3-A3 explained card. The AVR32 UC3 is a simple 32-bit microcontroller, that is similar to the AVR 8-bit microcontroller some of you already have experience with. Just as the 8-bit AVR, it can run C-code directly on the microcontroller without an operating system.

Despite this being a course about real-time operating systems, there are some things that are more easily demonstrated when programming bare-bones without an operating system. It also lets us establish a baseline for comparing performance and ease of programming when we in the next exercise will be using an operating system on the same platform.

This exercise will introduce the Butterfly Real-Time Tester (BRTT), which is an AVR evaluation kit modified to test the response times for external input events. We will be using the BRTT in several of the next exercises, so make sure to save your measurements in order to compare results in later exercises. REMEMBER TO BACK-UP ALL YOUR DATA WHEN YOU ARE FINISHED FOR THE DAY. Documentation for the BRTT can be found on Blackboard. Do not attempt to reprogram the Butterfly, as it might give incorrect results.

If you have questions or want to get your assignment approved, please apply for a spot (using your NTNU-user) in the queue here: <https://s.ntnu.no/rts>.

1 Developing with AVR32

1.1 Running test application

This exercise assumes that you use Atmel Studio 7 on Windows. You can download a template project on Blackboard (AVR32 Template.zip). This should be unzipped at a location of your choosing and the solution file opened in Atmel Studio 7. You will be prompted to update the project (it was originally made for Atmel Studio 6), do this. The AVR32 UC3 should be connected to the PC and JTAG as described in the Getting Started guide you can find on Blackboard, which is also demonstrated in Figure 1.

Additional information about the card can be found in the Hardware User's Guide. When the card is connected, you can click the outlined green play button in Atmel Studio ("Start without debugging, Ctrl+Shift+F5) to build the test application, program the card and run the application. If there is a message that the JTAG tool must be upgraded, just follow the instructions on screen.

When the program starts running on the card, a LED will start blinking every second. Instead of clicking the outlined green play button to run the program, you can also click the filled green play

button to start with debugging. If you have added any breakpoints, the execution will pause once you reach them (or you can manually pause at any time), and from there you can step through the code one line at a time.

1.2 Serial debugging

As you likely noticed, there is a call to `printf()` in the test application. The call to `stdio_usb_init()` directs the standard input and output streams to the usb-to-serial device, letting you print to a terminal on the lab PC.

Open the program Termite to read the serial output. Click settings, baud rate of 115200, 8 data bits, 1 stop bits, no parity or flow control. The COM port should be the last one, which is probably COM3. Click OK and then on the button on the top left of the main termite window to connect. It should now print “tick” every second, if not, you can disconnect and connect the usb cable to the AVR32 (restart it).

Unfortunately the AVR32 UC3 doesn’t behave exactly as a normal serial port. The problem is that if you now reprogram the AVR32 from Atmel studio, the print will stop working. The trick is to reprogram or restart the AVR32 while the Termite program is “waiting for port”. Printing will then work normally when the AVR32 starts running. To make the Termite waiting for port, disconnect and try to connect to the correct serial port while the AVR32 is not powered or while it is being programmed. Apart from the hassle of getting the printing to start properly, it should work as expected.

Remember that `printf()` is a slow function that will significantly influence the timing behavior of your program. Any prints used for debugging should be disabled when performing the response time tests.

1.3 AVR32 project description

The `main.c` file contains the `main()` function which runs when the application is started on the AVR32. This is the only file that you should edit in this exercise.

The `main.c` file starts with including `asf.h` (which again includes a large number of other header files) and `busy_delay.h` (which implements micro- and milli-seconds busy wait functions). The Atmel Software Framework (ASF) files are libraries that have functions you can use instead of doing low level register programming, as you would otherwise have done if programming an 8-bit AVR.

After the includes, there are several defines, the first one is necessary for USB to serial, while the rest define the general-purpose I/O pins of the J3 header that you will use in this exercise. The `init()` function initializes the LEDs and buttons on the card, the interrupts, USB to serial and busy wait delays. This function must be run at the start of the `main()` function, and should not be edited.

The `interrupt_J3()` function is a interrupt handler that can be configured to run based on the pins on the J3 header. This will be explained when interrupts are introduced. The `main()` function starts by running the `init()` function, which should always be there. After the point of calling `init()`, you can change the code as you like. Of the other files in the project, you only need to be aware of a few of them:

- The files in `asf/avr32/boards/uc3_a3_xplained` folder initialize the card.
- The files in `asf/avr32/drivers/gpio` defines functions for using the general IO pins of the card, including the J3 header which we will use to connect to the Butterfly.

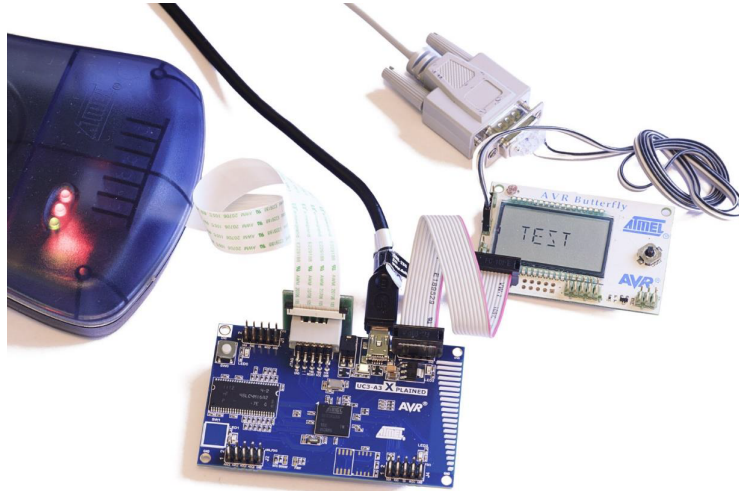


Figure 1: Demonstration of BRTT connection

- `busy_delay.c` and `busy_delay.h` are provided as easy to use busy wait delay functions. These are modifications of the original files for delaying found in `asf/avr32/services/delay`.

2 AVR32 UC3 reaction time

The BRTT reaction test measures the time a system uses to react to an external "real world" event. This is an important property of real-time systems. The BRTT can evaluate any system that has simple digital IO pins. In this course we will test different systems and techniques for responding to one or several signals as consistently as possible.

By doing the same test a large number of times, we will get a distribution of response time. For real-time systems, the worst-case response time will be more important than the average. If we consider a real-time system that controls the brakes of a car, an average response time of 1 ms is of no interest if the worst-case response time is so high that it will cause accidents.

We will use the BRTT to test the reaction time of the AVR32 UC3 device. The test consists of the BRTT sending signals that the AVR32 UC3 should notice and respond to as soon as possible.

2.1 Connecting the BRTT

Figure 1 shows how the Butterfly can be connected to the AVR32 card. This will both power the Butterfly and connect the necessary I/O pins. The Butterfly should also be connected to the PC with the provided cable and a normal serial cable. The BRTT prints the results of the test to the serial line, and you should use Termite to get hold of this data. The serial port is COM1 and the baud rate is 9600, the other settings should be default.

The BRTT folder on Blackboard contains a user manual and a spreadsheet for analyzing the results. The results are formatted so they can be pasted directly into the spreadsheet, which will show the distribution of response times in a histogram. Since you have to keep the results for comparison, it is suggested that you use Office 365 and their online excel program. This can be

| | D | E | F | G | H | I |
|----|---|---------------|------------|-----|-----|-----|
| 1 | | | | | | |
| 2 | | | Test name: | | | |
| 3 | | | Busy-wait | | | |
| 4 | | | | | | |
| 5 | | Reaction test | | | | |
| 6 | | type | A+B+C | | | |
| 7 | | number | 1000 | | | |
| 8 | | | | | | |
| 9 | | max value | 65536 | | | |
| 10 | | unit | us | | | |
| 11 | | | | | | |
| 12 | | test | A | B | C | |
| 13 | | | 0 | 949 | 17 | 26 |
| 14 | | | 1 | 778 | 833 | 843 |
| 15 | | | 2 | 206 | 272 | 262 |

Figure 2: Example of spreadsheet results

found by going to <https://innsida.ntnu.no/> clicking on the squares in the upper left corner → Office365 → OneDrive. You can upload and edit the template here.

Since the different systems we will test will have quite different response times, you will have to set an appropriate time scale. If you choose a scale that is too low, the results that are higher than the scale will be shown in the rightmost column. To see the whole distribution, the rightmost column should ideally be zero.

TASK A

The simplest way to respond to the reaction test is with a busy-wait that continuously reads the input pin, waiting to discover a signal. As the name implies, the program is busy while it is waiting for a signal, preventing the processor from being used for anything else that might be useful. Because of this, the busy-wait approach is usually avoided. We will start with a test of type A, meaning that only one signal is sent from the BRTT. The BRTT signals the AVR32 by setting the TEST A pin low. The AVR32 should then set the RESPONSE A pin low as soon as possible.

The pins for the BRTT are configured and used in the same way as the pins for controlling the LEDs on the card, which are found in `board_init()`. Try marking this function and pressing alt+g. This should show how this function is implemented, taking you to `/src/asf/avr32/boards/uc3_a3_xplained/init.c`. Then try looking up the source for `gpio_toggle_pin()` in the main function to find appropriate methods to read and writing the pins.

Create a program that uses the busy-wait technique to respond to a test of type A only. Here's some pseudocode to get you started:

```

loop forever:
wait until testA = 0
response A = 0
wait 5us // hold the signal a short while, so the BRTT can see it
response = 1

```

Perform a reaction test with the BRTT. When copy-pasting the results into the spreadsheet, it should look something like Figure 2.

Be careful to get row and columns correct, or it will not work. The "Paste here..." text should

be replaced with "Reaction test". In the graphs sheet you can see the time distributions of up to six different tests. You can also adjust the time scale, so the data fits well inside the graphs. There is also a compare sheet that is one large diagram comparing up to six tests.

TASK B

Extend your application, so it checks all three TEST signals (A, B and C) and sets the corresponding RESPONSE signal if a signal is detected. Do a reaction test with at least 1000 subtests of type A+B+C, and save the results in the spreadsheet.

The BRTT will make a noise when running a A+B+C test, because the pins used for the C test shares pins with the speaker on the back of the BRTT. This does not affect the test.

Compare the results from responding to only the A test and responding to all three.

Which one has the lowest variance?

The lowest maximum? Why?

Does the response for A, B and C look the same?

2.2 Interrupts

As mentioned before, busy-wait is generally avoided since it wastes CPU resources (and power). Using interrupts is often a preferred solution, especially for a platform like the AVR32 UC3 where interrupts are very easy to set up. If a pin is configured with an interrupt it is monitored without disturbing the rest of the program on the AVR32. When a signal is detected, the main process is paused and an interrupt handler function is called.

Half of the job of setting up an interrupt has already been done in the `init()` function and since the `interrupt_J3()` function has been prepared. In addition to this, you must register each of the pins you use as an interrupt, using the `gpio_enable_pin_interrupt()` function.

If you register more than one pin as interrupt, they will all run the same interrupt handler function. You must therefore check which of the pins have an active interrupt flag in the interrupt handler function, with the function `gpio_get_pin_interrupt_flag()`. When you have identified which gpio that has the active flag, it must be cleared using `gpio_clear_pin_interrupt_flag()`.

TASK C

Create a program that responds to the A+B+C test using interrupts instead of busy-wait. Save the results in the spreadsheet.

How do the timings compare to the busy-wait solution? Do A, B and C have the same response time? Why/why not?

2.3 Big while

Since interrupt handlers are run immediately, they are effectively "high priority tasks" that block other tasks (or other interrupts) from running. Therefore, it is generally good practice to spend as little time as possible in an interrupt handler. When responding to this reaction test, this is not really a concern since we only do a few things in the interrupt handler.

So let's just pretend that we have a time-consuming calculation to perform when an interrupt happens. In order to not block other interrupts from being handled, the interrupt handling for the "slow" events should only set a flag corresponding to the pin that got the signal. In the main function, we have a "big while loop" that checks for the different flags, and runs code for responding to the interrupt. Remember to clear the flag after use.

When a normal function and an interrupt are using the same global variable, it should be declared as volatile or else the compiler may make some optimization assumptions that aren't valid.

TASK D

Before trying this technique, stay with the interrupt technique you used previously in Task C, but make the processing of a type B event "expensive" by adding a call to `busy_delay_us(100)` before responding to it. Save the results.

Then create a program that responds to the A+B+C test using deferred interrupt handling in a big while loop. First do it without the extra "expensive" calculation for the B response, then with. Save both results.

Now compare all four scenarios: "expensive B" vs. "fast B" response, immediate processing in interrupts vs. deferred with a big while loop.

For the deferred technique: Is it faster or slower, and why?

For the "expensive B" response: Which solution had the least impact on the response for A and C?

TASK E (optional)

Combine any of the methods you used in this exercise to optimize your program for minimal and least variable response times for all A+B+C events, where the B event still includes the slow 100us "calculation".

REMEMBER TO BACK-UP ALL YOUR DATA WHEN YOU ARE FINISHED FOR THE DAY, AS THE RESULTS WILL BE NEEDED IN THE NEXT EXERCISE.