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task2 makes a LED blinks every one second. Binary semaphores are used to gain exclusive access to a single resource (like the serial port, a non- reentrant library routine, or a hard disk drive). Copy the RTX_Conf_CM.c (C:KeilARMRLRTXConfig) to the project folder and add it to your project. if (i == 9) { i = -1; } } } // toggles LED #7 at P2.6 every second __task void task2(void) { GLCD_DisplayString(4, 0, 1, "Task 2:LED"); for (;;) { LED_on(7); os_dly_wait(60); LED_off(7); os_dly_wait(40); } } // task that keeps incrementing a global counter __task void task3(void) { GLCD_DisplayString(5, 0, 1, "Task 3:"); for (;;) { g_counter1++; if (g_counter1 == 60) g_counter1 = 0; // reset; os_dly_wait(100); sprintf(text_buffer, "%d", g_counter1); GLCD_DisplayString(5, 7, __FI, (uint8_t*)text_buffer); } } // task that keeps decrementing a global counter __task void task4(void) { GLCD_DisplayString(6, 0, 1, "Task 4:"); for (;;) { g_counter2--; if (g_counter2 == 0) g_counter2 = 60; // reset; os_dly_wait(100); sprintf(text_buffer, "%d", g_counter2); GLCD_DisplayString(6, 7, __FI, (uint8_t*)text_buffer); } } // initialization task that spawns all other tasks __task void init(void) { os_tsk_create(task1, 1); // task 1 at priority 1 os_tsk_create(task2, 1); // task 2 at priority 1 os_tsk_create(task3, 1); // task 3 at priority 1 os_tsk_create(task4, 1); // task 4 at priority 1 os_tsk_delete_self(); // task must delete itself before exiting } 8. 2. You should not use RTX at all but your program should achieve the same behavior as RTX_Blinky example. Example 2: Simulating a stepper-motor driver a) Semaphores: MUTEX There are several types of semaphores (the basic idea behind each type is the same): Binary Counting Mutex Semaphores are typically used in one of two ways: 1) To control access to a shared device between tasks. Example 1: Creating an RL-RTX Application RTX programs are written using standard C constructs and compiled with the RealView Compiler. 2 3. Choose "RTX Kernel" as the operating system (default is set to None). This exercise is to outline the differences between RTX and Super-Loop embedded programming approaches. When a device wishes to print, it attempts to "take" the semaphore. For example, here is the description of os_mut_wait: 6. See how a mutex is utilized to control the access to the LCD display. Please read especially section 7, which describes other ways to switch tasks aside from the aforementioned Round Robin. There is also an abundance of information on ARM's website. The main_4tasks.c is also listed in Appendix A of this document. You can find it in C:KeilARMBoardsKeilMCB1700RTX_Blinky or inside the downloadable archive with the files of this lab. Let's now create a simple example project called lab6_ex1_4tasks and place it in a new folder called lab6_ex1_4tasks/. Also, remember to configure the CPU speed to 100 MHz by means of the RTX_Conf_CM.c configuration wizard. 3. Interrupt Service Routines (ISR) are used for time-critical program portions. It is one of the components of RL-ARM, the RealView Real-Time Library (RL-ARM). If you want to see how some of the os_* functions are implemented, read the RTX source code from C:KeilARMRLRTX/. 5. It provides additional functions for inter-task communication, memory management and peripheral management. This is also displayed on the LCD display of the MCB1700 board. Oldham, and A. You need to set the total number of tasks the system can manage. The main use of a Mutex is to control access to a chip resource such as a peripheral. If done correctly, you may get up to 3% of the final grade. 4 Now, run a simulation debug session and use the following debug features of uVision: RTX Tasks and System Window Click Debug -> OS Support -> RTX Tasks and Systems. 8 int main(void) { // (1) initialize the LPC17xx MCU; SystemInit(); // (2) initialize GLCD and LED; LED_init(); GLCD_Init(); LED_on(0); // turn on LED #0 at P1.28 GLCD_Clear(Yellow); GLCD_DisplayString(0, 0, 1, "RTX Hello World! :-)"); // (3) initilize the OS and start the first task os_sys_init( init); } task1 counts and displays digits 0-9 in a round robin fashion. The main features of RTX include: Royalty-free, deterministic RTOS with source code Flexible Scheduling: round-robin, pre-emptive, and collaborative High-Speed real-time operation with low interrupt latency Small footprint for resource constrained systems Unlimited number of tasks each with 254 priority levels Unlimited number of mailboxes, semaphores, mutex, and timers Support for multithreading and thread-safe operation Kernel aware debug support in MDK-ARM Dialog-based setup using µVision Configuration Wizard 4. Open the RTX_Conf_CM.c under the Configuration Wizard and set the CPU to 100000000. 1. RTX and its source code are available in all MDK-ARM Editions [1]. RTOS Simple embedded systems typically use a Super-Loop concept where the application executes each function in a fixed order. RTX allows one to create programs that simultaneously perform multiple functions (or tasks, statically created processes) and helps to create applications which are better structured and more easily maintained. Create a new uVision project and write a program using the Super-Loop approach discussed in this lab to implement Example 2. Event Viewer provides a graphical representation of how long and when individual tasks run. Lower priority tasks will not run. A RTOS separates the program functions into self-contained tasks and implements an on-demand scheduling of their execution. 5. For more details on the above, please take some time to read entirely the "Keil RTX RTOS: The Easy Way" tutorial [2]. The difference is that a Mutex is initialized with one token. After the // specified number of ticks has expired, the calling task will // be placed in the ready state. Observe operation and comment. The header file RTL.h defines the RTX functions and macros that allow you to easily declare tasks and access all RTOS features. A printer is a good example. 7 // processing time with a loop. Control will switch to the // next task ready else passes to the idle demon. First, we must declare the Mutex container and initialize the Mutex: os_mut_init (OS_ID mutex); Then any task needing to access the peripheral must first acquire the Mutex token: os_mut_wait (OS_ID mutex, U16 timeout); Finally, when we are finished with the peripheral, the Mutex must be released: os_mut_release (OS_ID mutex); Mutex use is much more rigid than semaphore use, but is a much safer mechanism when controlling absolute access to underlying chip registers. Advanced linux programming, 2001 (Chapter 4); -- Multithreaded Programming (POSIX pthreads Tutorial); -- MSDN Introduction to Mutex Objects; us/library/windows/hardware/ff548097(v=vs.85).aspx -- Lock-free programming; APPENDIX A: Listing of main_4tasks.c of Example 1 project // simple RL-RTX application to blink an LED and // to display 0-9 in a round robin fashion on LCD // display of MCB1700 board // this is meant to be a "hello world" example for // RTX application development; #include #include #include #include "GLCD.h" #include "LED.h" #define __FI 1 // Use font index 16x24 // global counters will count 60 seconds up and down; int g_counter1 = 0, g_counter2 = 60; char text_buffer[8]; // displays 0-9 in a round robin fashion __task void task1(void) { int i = 0; GLCD_DisplayString(3, 0, 1, "Task 1:"); for (;;i++) { GLCD_DisplayChar(3, 7, 1, i+'0'); os_dly_wait(100); // Note1: The Delay function pauses the calling task by the amount // of ticks passed as the argument. Higher priority tasks will preempt (or interrupt) a running task. For this reason, a Mutex token is binary and bounded. 4. Configure the project to use "RTX Kernel" as the operating system. Create a new project and use NXP LPC1768 as the target processor. An advanced RTOS, such as the Keil RTX, delivers many benefits including: Task scheduling - tasks are called when needed ensuring better program flow and event response Multitasking - task scheduling gives the illusion of executing a number of tasks simultaneously Deterministic behavior - events and interrupts are handled within a defined time Shorter ISRs - enables more deterministic interrupt behavior Inter-task communication - manages the sharing of data, memory, and hardware resources among multiple tasks Defined stack usage - each task is allocated a defined stack space, enabling predictable memory usage System management - allows you to focus on application development rather than resource management (housekeeping) 2. Counting semaphores are used when you might have multiple devices (like 3 printers or multiple memory buffers). Mitchell, J. RTX Event Viewer Click Debug -> OS Support -> Event Viewer. Mutex stands for "Mutual Exclusion" and is a specialized version of a semaphore. task4 keeps decrementing a global counter. By tasks taking and giving the same semaphore, you can force them to perform operations in a desired order. RL-RTX The Keil RTX (Real Time eXecutive) is a royalty-free deterministic RTOS designed for ARM and Cortex- M devices. Tasks can be assigned execution priorities. 5 Take some time to read more on: Mutex management routines in RTX: Building Applications with RL-ARM, Getting Started (included also in the lab files): b) RTX_Blinky Example This is the RTX_Blinky example that comes bundled with the Keil uVision software installation. Mutex semaphores are optimized for use in controlling mutually exclusive access to a resource. All these tasks are created with the same priority. Take some time and read the source code from blinky.c in order to get a good understanding of what's happening. These disadvantages of the Super-Loop concept are solved by using a Real-Time Operating System (RTOS). Now you can start to develop an RTX application. Then the system creates an initialization task named init which spawns four tasks task1, task2, task3, and task4. Objective The objective of this lab is to learn how to write simple applications using RTX (ARM Keil's real time operating system, RTOS). Lab assignment This is optional and available only to undergraduates in this course. The delay does not use up 7. In addition, we'll look at FreeRTOS too. Click Use MicroLIB in the code- generation window. Additional Mutex tokens cannot be created by tasks. In this example, four LEDs are blinking simulating the activation of the four output driver stages phase A,B,C,D. This is a simple RTX application that lights up the first LED when it starts and then displays the "Hello World!" string on the LCD screen. If the semaphore is available, the task gets to print. You can watch task switching and various system and task related information in this window. If the semaphore is not available, the task will have to wait for the printer. 1 Lab 6: Introduction to RTX Real-Time Operating System (RTOS) EE-379 Embedded Systems and Applications Electrical Engineering Department, University at Buffalo Last update: Cristinel Ababei, April 2013 1. Develop your program using only the programming techniques that we used earlier in this course. Open up the Target Option window and activate the "Target" tab. Start with the os_tsk_*() function reference which is within the µVision Help File. The RTX kernel uses the execution priorities to select the next task to run (preemptive scheduling). These limitations include the following disadvantages: Time-critical operations must be processed within interrupts (ISR) o ISR functions become complex and require long execution times o ISR nesting may create unpredictable execution time and stack requirements Data exchange between Super-Loop and ISR is via global shared variables o Application programmer must ensure data consistency A Super-Loop can be easily synchronized with the System timer, but: o If a system requires several different cycle times, it is hard to implement o Split of time-consuming functions that exceed Super-Loop cycle o Creates software overhead and application program is hard to understand Super-Loop applications become complex and therefore hard to extend o A simple change may have unpredictable side effects; such side effects are time consuming to analyze. Tasks of equal priority will be run in Round Robin when they enter the ready state. Apart from this, it really works in the same way as a semaphore. 2) Task synchronization. 4. Compile, and download to the board. Note: Examples that come with the Keil's uVision installation contain in their own project folders local copies of the RTX_Conf_CM.c, which may be different from the one in C:KeilARMRLRTXConfig due to their different time-stamps... 3. You don't want 2 tasks sending to the printer at once, so you create a binary semaphore to control printer access. A counting semaphore that has a maximum value of 1 is equivalent to a binary semaphore (because the semaphore's value can only be 0 or 1). Figure 1 RL-ARM Real-Time Library and RTX Real-Time Operating System diagrams. Credits and references [0] Building Applications with RL-ARM, Getting Started (included also in the lab files): [1] RTX Real-Time Operating System; -- -- -- -- -- -- 6. Like a semaphore, a Mutex is a container for tokens. These simple examples involve flashing LEDs, counting, and displaying on the board's LCD display a "simulation" of how to drive a step-motor. Note that, it might have been more intuitive if Round Robin Timeout had been called Round Robin Task Switching Time. This window updates as the RTX runs. There are several implementations of this type of semaphore. 6 [2] Robert Boys, Keil RTX RTOS: The Easy Way V0.4. 2012; [3] Irene Huang, ECE-254 Labs; yqhuang/labs/ece254/document.html [4] On mutexes; -- RL-ARM, Getting Started (Chapter 2): -- Daniel Robbins, Common threads: POSIX threads explained - The little things called mutexes; -- A.D. Mashall, Programming in C, UNIX System Calls and Subroutines using C, 2005 (Chapter on Mutual Exclusion Locks); -- M. 3 The following are the basic steps (in the context of this course) to create an application that uses RL-RTX library: 1. 7. This approach is well suited for small systems but has limitations for more complex applications. The entire uVision project folder is included in the downloadable archive for this lab. Note: A lot of the discussion in this lab is based on ARM's online information. This is located in the file RTX_Conf_CM.c. One can insert user code to run during this idle time. If no tasks are ready to run then RTX will execute its idle demon. The default value is 6 and normally is sufficient. task3 keeps incrementing a global counter. Samuel.

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