THE UNIVERSITY OF THE WEST INDIES
ST. AUGUSTINE

ALTERNATIVE ASSESSMENT FOR FINAL EXAMINATIONS OF December 2020

Code and Name of Course: **ECNG3006 Microprocessor Systems** Paper: **Final**

Date and Time: Duration:

INSTRUCTIONS TO CANDIDATES: This paper has 6 pages and 3 questions. Max. Marks: **100**

Attempt ALL questions.
Questions 1 and 2 are each worth 25 marks.
Question 3 is worth 50 marks.

Read the ENTIRE question paper before starting.
Please hand-write your answers,
clearly in a legible and readable manner (see Submission Instructions).
Queries regarding this question paper should be addressed to the Examination Invigilator.

The following reference information is available for use during this exam:

- Description of a "Domestic Leak Detection and Usage Monitoring System" on pages 5-6
- Quotes from national press re: WASA:
  "we've done some work [to] accurately diagnose how much water is lost through leakages and so forth. Best estimates, its approximately 40 to 45 per cent ..., said [WASA CEO] Thomas ...not all those leaks were directly related to faulty WASA lines, but also occurred on domestic properties which the utility had little control over. ...it was difficult to properly ascertain how much water was actually wasted as a result. " [1]
  "The WASA Act (section 49 (1)) says in times of a serious deficiency of water WASA may for as long as needed prohibit or restrict the use of its supply for watering private gardens or washing private motor cars by hosepipe. A breach brings a fine of $750 on summary conviction, plus $75 each day the offence continues (section 83.)" [2]

[1] Peter Christopher, Trinidad Guardian Feb 2020 `https://www.guardian.co.tt/news/wasa-leaks-account-for-wastage-of-half-water-supply-6.2.1054290.eb6659a1dd`

[2] Sean Douglas, Trinidad Newsday Dec 2019 `https://newsday.co.tt/2019/12/29/wasas-christmas-challenge-faulty-pumps-affect-water-supply/`

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Submission Instructions

In submitting a response to this question paper, students are required to:

1) write their UWI Students Registration ID Number at the top of each page on their script.
2) write the Course Code and Name of the Course in UPPERCASE at the top of each page
3) number each page of their script - for example, if six pages were used, the pages should be numbered as 1 of 6, 2 of 6 and 3 of 6 etc. The Page numbers should be written at the top right hand side of each page
4) start each question on a new page
5) write on only one side of each page to ensure that a clear scan of their work can be made.
6) scan, or take photos of, their scripts and save the document as a multi-page PDF file - the file name must be the UWI Students Registration ID Number - for example 8123456789.pdf
7) review the scanned PDF document before upload to ensure that:

- The pages are in order, and are oriented correctly
- The writing is clear and readable
- All pages are included in the scanned PDF Document
- Your name does NOT appear anywhere within the PDF document

8) upload the PDF file in the appropriate area in myeLearning, AND click the submission button, BEFORE the stipulated deadline.

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Q1. FreeRTOS is an example of a open-source real-time operating system (RTOS) kernel which supports both mutexes and semaphores, as well as both co-operative, and pre-emptive, priority based multi-tasking systems.

(a) Explain, in your own words, the operation of a FreeRTOS application, with two independent tasks, that uses a pre-emptive tick-based Round-Robin scheduler and contrast it's operation to that of a co-operative multi-tasking system. *5 marks*

(b) Identify one benefit, and one drawback, of utilising coding standards in developing embedded systems that use FreeRTOS. Support your answer(s) by explaining the rationale for the AUTOSAR Rule A15-0-7:
"Exception handling mechanism shall guarantee a deterministic worst-case time execution time."[3]. *5 marks*

(c) If a task is taking too long to execute, what steps can be taken using FreeRTOS to eliminate or reduce any undesirable side-effects? *5 marks*

(d) Describe how the proportion of time that tasks are running (i.e. CPU Utilization) can be determined within the FreeRTOS kernel. *5 marks*

(e) Identify two advantages/disadvantages of utilising open-source kernels (vs. closed-source commercial or proprietary kernels) to implement real-time system(s). Support your answer by referring to case studies of embedded system failure. *5 marks*

[Q1 Total 25 marks]

Q2. A high-reliability temperature monitor for a refrigerator that is part of a vaccine cold-chain, consists of an ESP8266, one to four analogue temperature sensor(s), and a serial display. Temperature sensors, are connected via front end circuitry to a dedicated external analog to digital converter (ADC). Each ADC produces approximately ten samples per second for the temperature sensor that is connected. Samples are read by the ESP8266 using an interrupt driven foreground task. Samples are stored using 64-bit fixed point representation. The serial display is updated, every minute, from the cyclic executive running as the background task. To update the serial display, an 80-byte string is transmitted via the UART. The string contains the minimum and maximum temperatures recorded across all sensors.

(a) The ESP8266 micro-controller is based on the 32-bit Tensilica XTensa L106 Architecture. Identify at least two assembly-language instructions, or architectural features, that would support the high-reliability temperature monitor as described. *5 marks*

[3]page 274, Guidelines for the use of the C++14 language in critical and safety-related systems`https://www.autosar.org/fileadmin/user_upload/standards/adaptive/18-10/AUTOSAR_RS_CPP14Guidelines.pdf`

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(b) For the high reliability temperature monitor, determine the maximum rate at which an 80-byte message reading can be transferred by the UART if the ESP8266 output pin rise/fall time is $t\mu s$. Explain your reasoning. *5 marks*

(c) What are the characteristics that differentiate foreground from background tasks? Use the high-reliability temperature monitor to support your answer(s). *5 marks*

(d) What effect will the front-end circuitry and ADC have on the effective number of bits (ENOB) of stored temperature readings? What information about the temperature sensors, and the raw analogue signal(s) they produce, is needed to quantify the ENOB? *5 marks*

(e) *"The use of interrupt routines introduce the problem of critical data."* Explain the rationale for making this statement, and state whether you agree or disagree. Use the high-reliability temperature monitor to illustrate your point(s). *5 marks*

[Q2 Total 25 marks]

Q3. All questions in Q3 are based on "Description of a Domestic Water Leak Detection and Usage Monitoring System" on pages 5 - 6.

(a) Using the information provided, draw the precedence graphs for Tasks A, B, C and D, determine the Worst-Case Execution Time for each task, calculate the Worst-Case System Utilization, and comment on whether the system is feasible. *10 marks*

(b) Jobs for the Domestic Water Leak Detection and Usage Monitoring System are scheduled using fixed priorities with a pre-emptive priority based scheduler (see page 5). Construct worst-case task and resource timelines for the 150 ms of operation after system reset, in the case where Task D has highest priority, Task C has a mid-level priority, Task A has lowest priority and Task B is interrupt-driven. *15 marks*

(c) In question Q3.b, the system assigned specific priorities to the tasks. Alternatively, task priorities could be assigned using **rate-monotonic** static scheduling, or **shortest job first** dynamic priority scheduling. State, on the basis of three (or more) performance criteria, which priority assignment scheme you would recommend, and justify your recommendation in terms of the application context, and predicted system/task operation. *15 marks*

(d) Data, collected from the system described via WiFi, could be used by WASA (see quotes on page 1) to quantify water lost due to domestic leaks, and water mis-used during water-restrictions. Identify two operational issues and/or ethical concerns an engineer should consider BEFORE modifying firmware to allow remote retrieval of data. Suggest mitigating strategies for each issue/concern. *10 marks*

[Q3 Total 50 marks]

END OF QUESTIONS

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Figure Q3: Domestic Water Leak Detection and Usage Monitoring System

A domestic water leak detection and usage monitoring system is designed for private use by a property owner to manage the risk of property damage through the unintended loss of potable water, when the property is unoccupied. The physical system consists of the ESP-01s (ESP8266 platform variant), a relay-triggered normally-closed shutoff valve (connected to GP3 - with an actuation time of 500ms), and a pipe-clamp-on instrument consisting of two ultrasonic transducers mounted opposite a passive reflector.
The individual transducers are excited by a fixed 1MHz oscillating signal when the pins GP0 and GP2 output a HIGH respectively, and when not externally excited, will resonate and produce a HIGH (via smoothing circuitry) at the pins GP0 and GP2 respectively when they receive a 1MHz oscillating signal. The measurement firmware, is based around the principle of contra-propagating transit time for ultrasonic pulses. This principle suggests that the flow-rate for water passing through the pipe on which the instrument is clamped, given constant water pressure, and no air in the pipe, is **proportional** to:

- a constant dependent upon the physical dimensions of the clamp-on instrument,
- the internal cross-sectional area of the pipe,
- the square of the speed of sound in water at the ambient temperature
- the difference in propagation time for ultrasonic pulses in the up-flow and down-flow directions

Because there is no need to calculate the actual volume of water, in this application, the algorithm will make use of the difference in propagation time as a proxy for flow-rate, i.e.

- 1MHz burst of 20 μs duration is sent from GP0, and the time taken to arrive at GP2 is recorded t_{up},
- 1MHz burst of 20 μs duration is sent from GP2, and the time taken to arrive at GP0 is recorded t_{dn},
- the time measurements are translated into a proxy-flow-rate using the equation $t_{up} - t_{dn}$
- the minimum and maximum observed values of proxy-flow-rate over time are tracked

The shutoff valve will remain closed as long as the system is off, or has detected a leak. The system must be reset in order for the shutoff valve to open. A pipe on the property must be opened before the system is reset, and can be closed 5 seconds after the system has been reset. Leak detection starts 5 minutes after the system has been reset. A leak is detected if the proxy-flow-rate has been:

- greater than 10 times the maximum proxy flow rate previously observed, for over 5 seconds
- at the minimum proxy flow rate observed, for over 5 minutes

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The ESP8266 SDK with FreeRTOS is used as the basis for the firmware.

- The kernel will be configured to
  - allow interrupt events to preempt the running task
  - perform pre-emptive priority-based scheduling, where tasks with equal priority do not pre-empt each other.
  - trigger an immediate scheduler call when a running task transitions to the waiting state
  - incur negligible overhead at system reset, and scheduler task switch
- The following tasks will be used to implement the system:
  - Task A a periodic task that is responsible for triggering the pulse on GP0 or GP2
  - Task B a sporadic (interrupt-driven) task which is triggered by an incoming signal from GP0 or GP2 i.e. it measures t_{up} in one instance and t_{down} in the next instance;
  - Task C a periodic task that detects leaks occurring and closes the shutoff valve if needed;
  - Task D a one-off task that occurs on startup, responsible for initially opening the shutoff valve.
- Tasks A and B use a global variable r to specify the direction in which a measurement is taken
- Task B queues a message containing the direction r and the transit time t associated with the latest measurement. Task C processes the messages to detect leaks.
- Tasks C and D use a mutex to manage access to the shutoff valve.

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Task Name	Operation, Jobs, and Estimated Times

A	job(s) released periodically every 10ms
	r is a global variable
	change direction: r = ((r==0)?1:0) (JAa, e=1 μs)
	if (r==0)
	set GP0 as output pin and GP2 as input pin triggering ISR (JAb, e=22 μs)
	output HIGH on GP0 and reset/start hardware timer
	busy-wait for 20 microseconds
	output LOW on GP0
	else
	set GP2 as output pin and GP0 as input pin triggering ISR (JAc, e=22 μs)
	output HIGH on GP2 and reset/start hardware timer
	busy-wait for 20 microseconds
	output LOW on GP2
	enable input pin interrupts (JAd, e=1 μs)

B	job(s) released sporadically by an interrupt triggered from GP0 or GP2, never sooner than 1ms after burst transmission r is a global variable; t is a static variable disable the input pin interrupts (JBa, e=4 μs) read hardware timer value and store in variable t queue message based on t and r

C	job(s) released periodically every 100ms
	maxflow and minflow are global variables of type integer
	while (queue.count > 1) (JCa, e=1ms
	retrieve two measurements from the queue (JCb e= 1-14ms)
	if measurements are not in the same direction
	calculate the proxyflowrate = $t_{up} - t_{dn}$
	if (minflow is less than proxyflowrate)
	minflow=proxyflowrate
	if (maxflow is less than proxyflowrate/10) or (maxflow==0)
	maxflow=proxyflowrate
	countmax = (proxyflowrate is greater than maxflow)? countmax+1: 0
	countmin = ((proxyflowrate == minflow)and (minflow!=0))? countmin+1:0
	if acquire mutex for the shutoff valve (timeout after 1 ms) (JCc, e=1)
	if (countmin > 5seccount) or (countmax > 5mincount) (JCd e =1 - 5ms)
	close shutoff valve
	release mutex for shutoff valve

D	job(s) released once at t=0; deadline=100ms maxflow and minflow are global variables of type integer if acquire the mutex for the shutoff valve (no timeout) (JDa, e=1ms) open the shutoff valve (JDb, e=3ms) set maxflow = 0 set minflow = largest value timer can hold sleep for 5 minutes (JDc, e=1ms) release the mutex for the shutoff valve (JDd, e=1ms)

END OF EXAM PAPER