[ENG82]

UNIVERSITY OF GREATER MANCHESTER

SCHOOL OF ENGINEERING

MSc ELECTRICAL & ELECTRONIC ENGINEERING

SEMESTER 2 EXAMINATIONS 2024/25

PERVASIVE EMBEDDED SYSTEM DESIGN

MODULE NO: EEE7007

Date: 14 MAY 2025 **Time: 10:00 – 13:00**

INSTRUCTIONS TO CANDIDATES:

There are SIX questions.

You should answer ANY FOUR questions.

All questions carry equal marks.

Marks for parts of questions are shown in brackets.

Electronic calculators may be used if data and program storage memory is cleared prior to the In-Class Assessment.

CANDIDATES REQUIRE:

Calculator.

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Question 1:

A. A smart environmental monitoring system is deployed in an urban area to measure temperature, humidity, and air quality. The sensors in the system generate analog signals, which must be converted into digital values using an Analog-to-Digital Converter (ADC) before being processed by a microcontroller.

i. Explain why an analog-to-digital converter (ADC) is necessary in pervasive computing systems.

[2 marks]

ii. Define the term "step size" in the context of ADCs and explain its significance.

[3 marks]

B. A temperature sensor outputs an analog voltage between 0V and 5V. It is connected to a 10-bit ADC with a reference voltage Vref of 5V.

i. Calculate the step size of this ADC.

[4 marks]

ii. If the sensor outputs 2.75V, what is the corresponding digital output in decimal form? Show your calculations.

[6 marks]

C. Consider an 8-bit ADC where Vref is adjustable. If Vref is changed from 5V to 2.5V:

i. How does the step size change?

[2.5 marks]

ii. Explain how this change impacts the precision of the digital output.

[2.5 marks]

D. The smart environmental monitoring system requires high precision in temperature sensing. Would you recommend using an 8-bit ADC or a 12-bit ADC? Justify your answer by comparing their step sizes and potential impact on measurement accuracy.

[5 marks]

[Total = 25 marks]

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Question 2:

A. You are tasked with developing a prototype for an embedded system using the STM32 NUCLEO-F446RE microcontroller, which is based on the ARM Cortex-M4 processor. The system requires the implementation of a digital signal processing (DSP) algorithm for real-time audio processing. Additionally, you aim to enhance the system with a basic machine learning model to classify audio signals into three categories: speech, music, and noise.

1. **DSP Algorithm Implementation**: Given the Cortex-M4's capability for efficient execution of DSP instructions, explain how you would leverage its features for optimizing the execution of a Fast Fourier Transform (FFT) algorithm used in your audio processing application. Consider the use of Single Instruction, Multiple Data (SIMD) instructions and floating-point unit (FPU) in your explanation.

[5 marks]

2. **Machine Learning Integration**: Using STMicroelectronics' X-CUBE-AI library, describe the process of integrating a pre-trained neural network model into the STM32 NUCLEO-F446RE for classifying audio signals. Outline the steps from converting the model to integrating it with your system, and how you would utilize the library's functions for running inferences directly on the device.

[5 marks]

3. **Debugging Features Utilization**: Discuss how you would use the advanced debugging features of STM32 NUCLEO-F446RE, specifically the real-time variable watch, to troubleshoot and optimize the performance of your DSP algorithm and machine learning model integration. Explain the advantages of being able to watch variables in real-time without halting the processor.

[5 marks]

B. Explain the role of the memory management unit (MMU) in the ARM Cortex-M architecture. Discuss the benefits of using an MMU in embedded systems and how it can be used to protect against security threats.

[10 marks]
[Total = 25 marks]
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Question 3:

A. Please answer all parts of the question below:

a) Discuss the interrupt handling mechanisms used in the ARM Cortex-M architecture.

[2.5 marks]

b) Explain how interrupts are prioritized, how they are handled, and how they are serviced by the CPU.

[15 marks]

c) Give an example of how interrupts could be used in an embedded system.

[2.5 marks]

B. Describe and explain the different power modes available on the ARM Cortex NUCLEO F446RE.

[5 marks]

[Total = 25 marks]
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Question 4

You are tasked with optimizing a data acquisition system that utilizes the STM32 NUCLEO F446RE microcontroller. The system is designed to monitor environmental parameters, including temperature, humidity, and light intensity, using three separate sensors. Due to the nature of the environment being monitored, data must be collected precisely every 200 milliseconds. However, the current setup experiences timing inaccuracies due to the system's inability to consistently manage the sampling rate. To address this challenge, you decide to implement an interrupt-driven mechanism that ensures accurate and consistent data sampling every 200 milliseconds. Your solution must not only correct the timing inaccuracies but also efficiently manage the microcontroller's resources.

1. Calculate the exact timer frequency needed to trigger an interrupt for data sampling every 200 milliseconds.

[2 marks]

2. Given the STM32's clock speed is 180 MHz, determine the appropriate prescaler and timer period values to configure the timer such that it generates an interrupt exactly every 200 milliseconds.

[8 marks]

3. Assuming the execution time of the Interrupt Service Routine (ISR) for data sampling and processing is estimated to be 1 millisecond, discuss the implications this has on the system's ability to perform real-time data acquisition and processing. Consider the microcontroller's clock speed and the timer configuration calculated in part 2.

[5 marks]

4. Justify the use of interrupts over polling in this scenario, particularly in terms of CPU resource management and system efficiency.

[5 marks]

5. Based on your calculations and the system requirements, propose a detailed solution that utilizes interrupts to achieve precise and consistent data sampling. Your solution should include the timer frequency, prescaler and period settings for the timer, and an explanation of how these settings ensure accurate timing. Additionally, discuss the advantages of using interrupts for this application, considering ISR execution time and overall system efficiency.

[5 marks]

[Total = 25 marks]

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Question 5:

A. Explain the difference between analogue and digital signals in embedded systems. What are the advantages and disadvantages of using each type of signal in an embedded system? Provide an example of a situation where one type of signal would be preferable over the other.

[7 marks]

B. Suppose you are working on an embedded system that uses an ADC to convert an analogue signal to a digital value. The ADC has a resolution of 12 bits and a reference voltage of 3.3 volts. If the input analogue signal ranges from 0 to 2 volts, what is the step size of the ADC?

- **Resolution of ADC**: 12 bits
- **Reference Voltage**: 3.3 volts
- **Input Analog Signal Range**: 0 to 2 volts.

[3 marks]

C. Consider an embedded system designed for precision temperature monitoring in an industrial oven, where accurate and noise-immune measurements are crucial for material processing.

i. Explain how analogue and digital signals differ in representing temperature variations in this context.

ii. Evaluate the benefits and potential drawbacks of utilizing each signal type for this specific application.

iii. Provide an example illustrating why one type of signal might be preferred over the other for ensuring precise and reliable temperature control within the oven.

Ensure your discussion reflects an understanding of the fundamental characteristics of analogue and digital signals, their processing requirements, and their suitability for precise environmental monitoring in industrial settings.

[15 marks]
[Total = 25 marks]
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Question 6:

A. Suppose you are working on an embedded system that uses a digital-to-analogue converter (DAC) to convert a digital signal to an analogue voltage. The DAC has a resolution of 10 bits and an output voltage range of 0 to 5 volts. If the digital signal is represented by the value 512, what is the corresponding output voltage?

[5 marks]

B. Signal conditioning is essential in STM32 microcontroller-based embedded systems for ensuring accurate and reliable data processing.

1. Discuss the importance of signal conditioning in bridging the gap between analogue signals and STM32 digital processing capabilities.

[3 marks]

2. Outline key signal conditioning techniques in STM32 systems, including:

- Filtering: Role in noise reduction.
- Amplification: Boosting sensor signals for ADC processing.
- Isolation: Protecting the microcontroller from high voltages.
- Linearization: Simplifying the processing of non-linear sensor outputs.

[8 marks]

3. Describe a scenario where signal conditioning is critical, such as temperature monitoring in precision manufacturing, highlighting potential accuracy issues without it.

[9 marks]

Focus on how signal conditioning supports data integrity and system performance in STM32-based applications.

[Total = 25 marks]

END OF QUESTIONS