Name: .....
Student Number .....

Software Engineering 4A03

DAY CLASS — Dr. Mark Lawford
DURATION OF EXAMINATION: 3 Hours
McMaster University Final Examination — December 2001

THIS EXAMINATION PAPER INCLUDES 4 PAGES AND 4 QUESTIONS. YOU ARE RESPONSIBLE FOR ENSURING THAT YOUR COPY OF THE PAPER IS COMPLETE. BRING ANY DISCREPANCY TO THE ATTENTION OF YOUR INVIGILATOR.

Special Instructions: The use of your course notes, and the required text books for this course are permitted during this exam. You may use any calculator. Answer all questions in the provided answer booklets. Fill in your name and student number and sign each booklet you use. This paper must be returned with your answers.

1. Control Systems Design (25 marks)

You have been assigned to work on the controls software for a new car that is powered by an electric motor. After considerable effort the automotive engineers have come up with a simplified model for the engine:

$$G(s) = \frac{3}{s(s+3)}$$

You have been asked to do a digital control design for the setting shown in Figure 1.

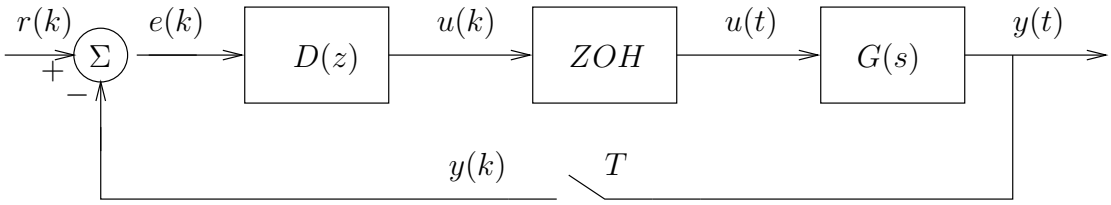

Figure 1: Block diagram for Question 1.

a) (5 marks) Assuming a sampling rate of T, find the ZOH discrete equivalent $G_{ZOH}(z)$ system for $G(s)$. This represents the discrete transfer function from $u(k)$ to $y(k)$.

b) (2 marks) What is the transfer function for $G_{ZOH}(z)$ when $T = \frac{1}{30}$?

c) (8 marks) What is the (open loop) impulse response of $G_{ZOH}(z)$ when $T = \frac{1}{30}$?

d) (5 marks) What is the (open loop) response of the system $G_{ZOH}(z)$ to the input:

$$u_k = \begin{cases} 2, & k = 1 \\ -2, & k = 2 \\ 0, & \text{otherwise} \end{cases}$$

(HINT: The discrete system we are considering is LTI!)

Continued on page 2

e) (2 marks) Let $D(z) = K$. Compute the closed loop transfer function for the discrete system transfer function from $r(k)$ to $y(k)$.

f) (3 marks) It is decided to try to stabilize the system using proportional control (i.e., $D(z) = K$). Sketch the discrete root locus for the system for $K > 0$ when $T = \frac{1}{30}$.

2. Control Systems Design II: PWM (25 marks)

Assume that the motor $G(s) = \frac{3}{s(s+3)}$ from question 1 is now placed in a continuous control loop with $D(s) = K$ as show in Figure 2:

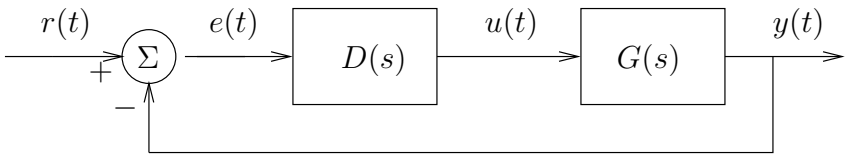

Figure 2: Block Diagram for Question 2

a) (5 marks) Sketch the root locus for $K > 0$. Are there any significant differences between the continuous control loop of Figure 2 and the digital control loop of Figure 1? Why?

b) (10 marks) The reference signal $r(t)$ to the continuous control loop is to be generated as a Pulse Width Modulated (PWM) signal to save the cost of an A/D converter.

i) Compute the closed loop transfer function, $G_{cl}(s)$, of the of the system when $D(s) = \frac{3}{4}$.

ii) For a reference input $r(t)$ with a pulse width of 50% of the period T_{pwm}, sketch $|G_{cl}(j\omega)|$ and signals $|R(j\omega)|$ and $|Y(j\omega)|$ to explain how PWM works.

c) (5 marks) Sketch the input signal $r(t)$ and output signal $y(t)$ in the case when T_{pwm} is chosen incorrectly so that first harmonic of the PWM signal is insufficiently attenuated.

d) (5 marks) If the discrete controller back in Figure 1 of this question were to use a PWM control signal $u(t)$ to control the motor, how would you consider modifying the block diagram to help reduce the effects of aliasing?

Continued on page 3

3. Control Systems Implementation I (30 marks)

a) (10 marks) Define in one or two points the following terms:

i) Kernel module

ii) Context switching time

iii) Interrupt service routine

iv) Jitter

v) Nyquist Frequency

b) (5 marks) The code fragment shown in Figure 3 is taken from the RTAI real-time Linux source for the file `/usr/src/rtai/include/asm-i386/rtai_sched.h`.

```
#define __STR(x) #x
#define STR(x) __STR(x)

#define rt_switch_to(tsk) \
        __asm__ __volatile__( \
        "pushl %%eax\n\t" \
        "pushl %%ebp\n\t" \
        "pushl %%edi\n\t" \
        "pushl %%esi\n\t" \
        "pushl %%edx\n\t" \
        "pushl %%ecx\n\t" \
        "pushl %%ebx\n\t" \
        "movl "SYMBOL_NAME_STR(rt_current)", %%edx\n\t" \
        "pushl $1f\n\t" \
        "movl %%esp, (%%edx)\n\t" \
        "movl (%%ecx), %%esp\n\t" \
        "movl %%ecx, "SYMBOL_NAME_STR(rt_current)"\n\t" \
        "ret\n\t" \
"1:     popl %%ebx\n\t \
        popl %%ecx\n\t \
        popl %%edx\n\t \
        popl %%esi\n\t \
        popl %%edi\n\t \
        popl %%ebp\n\t \
        popl %%eax\n\t" \
        : \
        : "c" (tsk));
```

Figure 3: Excerpt from `rtai_sched.h`

i) What is does the `rt_switch_to(tsk)` macro do?

ii) Typically real-time schedulers make use of macros and inline functions. Why?

c) (5 marks) The servos we used in Lab 3 could track steps represented as a PWM reference signal. For your PWM signal API design from Lab 3 you should have had some method of generating

Continued on page 4

interpolation points to have the servo track different waveforms. **Briefly** discuss the relative merits of generating these interpolation points in a real-time module vs. a Linux process.

d) (10 marks) You are getting grilled in a job interview by a company that was interested in your successful completion of 4A03. The interviewer wants to know when you would recommend using a real-time Linux variant (e.g. RTAI Linux) running on standard PC hardware and when you would use something else for an embedded system.

Discuss, with examples to illustrate your points, how you would answer this question and get the job!.

4. Scheduling (20 marks)

Consider the following 5 independent tasks with the specified periods:

Task	Period	Max. Execution Time
A	30	5
B	4	1
C	10	2
D	8	1
E	20	1

a) (10 marks) Draw a timeline showing how an EDF (Earliest Deadline First) policy would attempt to schedule the tasks for $t = 0$ to 30, assuming that all tasks start at time $t = 0$ and have a deadlines at the end of each of their specified periods.

b) (5 marks) Is it possible to schedule the tasks if they are preemptable?

c) (5 marks) Briefly discuss the advantages and disadvantages of Pre-Runtime Scheduling vs. schemes such as Rate Monotonic or EDF scheduling.

"Can the we make the final exam 100% for this course?" - 4A03 student after getting back the midterm

The End