(FY2010)

Instruction: Mechano-Informatics (Subject)

Answers should be written either in Japanese or English.

1) Do not open this problem booklet until the start of the examination is announced.
2) Among four problems provided, choose and answer two.
3) If you find missing, misplaced, and/or unclearly printed pages in the problem booklet, notify the examiner.
4) Two answer sheets are provided. Check the number of them, and if you find excess or deficiency, notify the examiner. You must use a separate sheet for each problem. When you run short of space to write your answer on the front side of the answer sheet, you may use the back side by clearly stating so in the front side.
5) In the designated blanks at the top of each answer sheet, write examination name (科目名) "Mechano-Informatics (Subject)", "Master" or "Doctor" (修士・博士), your applicant number (受験番号), and the problem number (問題番号). Omission in filling up these blanks may void your test score. Filling in the number of sheets (枚／枚中) is unnecessary.
6) An answer sheet is regarded as invalid if you write marks and/or symbols unrelated to the answer.
7) Submit both answer sheets even if they are blank.
8) Use the blank pages in the problem booklet for your draft.
9) Fill in your applicant number on the blank below, and submit this booklet. Also submit the Japanese booklet with your applicant number in the corresponding blank.

Applicant number:

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Problem 1

Consider a servo motor system. Answer the following questions.

P. 1. Consider a forward/reverse motor drive circuit as shown in Fig. 1. When answering, not only show the result but also explain the details reaching to each result.

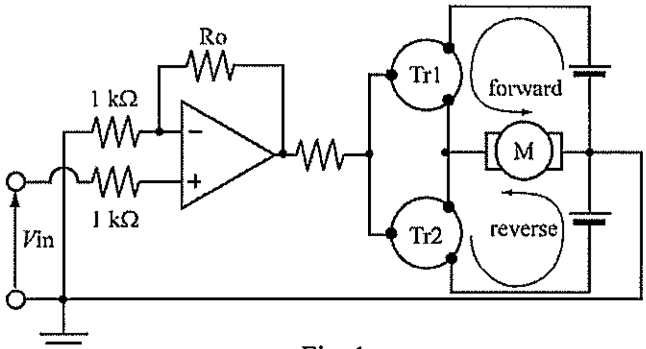

Fig. 1

(1) Determine the resistance value of Ro so that *V*in is amplified ten times by the operational amplifier.

(2) Show the circuit symbols of transistor Tr1 and Tr2, when the motor rotates in forward or reverse direction according to the positive or negative value of *V*in, respectively. Also answer their transistor types: PNP or NPN.

(3) In this circuit, the motor does not rotate when *V*in takes within a certain range. Explain why with 1 or 2 lines.

(4) Assume that the motor rotates at a steady state rotational speed of 150[rpm] in forward direction with the torque of 0.05[Nm] when we apply 12[V] at 0.17[A] across the motor. Calculate the efficiency of the motor (ratio of the output of the motor to the power consumption). Also assuming that a 14V battery is used as the power-supply at this time, derive the dissipation power of transistor Tr1.

P. 2. Figure 2 shows an equivalent circuit of a DC servo motor. Note that the input voltage to the coil in the armature of the motor is $v(t)$, the current is $i(t)$, the inductance of the coil in the armature is L, its resistance is R, the torque generated by the motor is $\tau(t)$, the rotational angle is $\theta(t)$, the total inertial moment of both the load and armature is J, and the coefficient of viscous damping regarding the rotational motion is b.

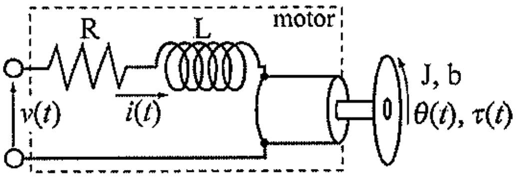

Fig. 2

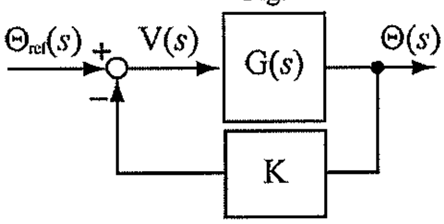

Fig. 3

(1) The counter electromotive force generated by the rotation of the motor is proportional to the angular velocity. Let this constant of proportion be Kv. Obtain a differential equation regarding the input voltage, the current, and the angular velocity.

(2) The generated torque is proportional to the current. Let this constant of proportion be Kt. Obtain the transfer function when the current is an input, and the rotational angle is an output.

(3) Obtain the transfer function $G(s)$, when the input voltage of the motor is an input and the rotational angle is an output.

(4) When R=1[Ω], L=0.2[H], J=0.01[$\mathrm{Nm \cdot s^2/rad}$], b=0.1[Nm·s/rad], Kt=0.01[Nm/A], and Kv=0.01 [V·s/rad], draw a schematic view of the gain diagram of $G(s)$ with necessary numerical values. Assume that the product of Kt and Kv is small enough to be ignored.

(5) Assuming that the angular sensor is installed in this motor, consider the angle control system as shown in Fig. 3. $V(s)$ and $\Theta(s)$ denote the Laplace transforms of $v(t)$ and $\theta(t)$, respectively. A constant reference value of $\Theta(s)$ is represented by $\Theta_{ref}(s)$. Derive the condition(s) of K that stabilizes the system. Assume that each constant is the same value as in (4).

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Problem 2

P. 1. As shown in Fig. 1, a uniform one-link arm, with length ℓ and mass m, rotates about O. The rotation angle is θ, and the acceleration of gravity is in the direction of $-z$ axis with amplitude g. Answer the following questions.

(1) Obtain the moment of inertia I_G about the center of gravity of the link.

(2) Obtain the kinematic energy K and the potential energy P of the system.

(3) Let a Lagrange function be $L = K - P$. Show the Lagrange equation of motion and calculate the torque τ about O.

Meanwhile, consider solving τ by the motion equation regarding the equilibrium of force.

(4) Obtain the acceleration $[\ddot{x}_G \ \ddot{z}_G]^T$ of the center of gravity of the link.

(5) When the link rotates, obtain the relationship among translational / angular inertia forces at the center of gravity of the link, the gravity force, constrained force f_x, f_z at O, and torque τ. Then, calculate τ.

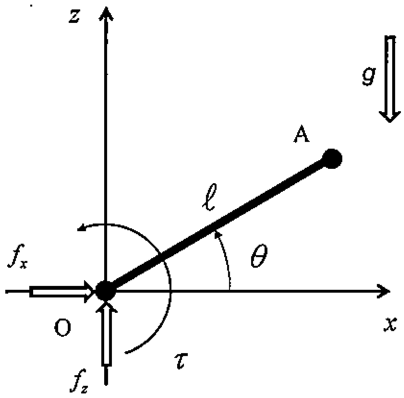

Fig. 1

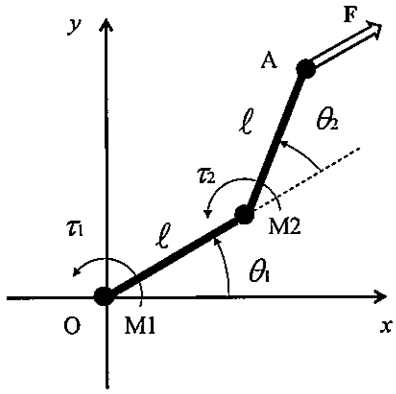

Fig. 2

P. 2. As shown in Fig. 2, a 2-link arm is located on the horizontal plane and torques τ_1, τ_2 are produced at the joint M1 and M2, respectively. Two links of length ℓ rotate with angle θ_1, θ_2. Answer the following questions.

(1) Let the tip position A of the arm be represented by $[x_A \ y_A]^T$. Describe $[x_A \ y_A]^T$ using θ_1, θ_2 and ℓ.

(2) Assuming $\ell = 1$ and $\theta_1 = \theta_2 = \pi/6$, calculate small rotation angle $[\Delta\theta_1 \ \Delta\theta_2]^T$ that provides small displacement $[\Delta x_A \ \Delta y_A]^T$ of point A.

(3) Suppose the 2-link arm is in static equilibrium. When force $\mathbf{F} = [f_x \ f_y]^T$ is applied to point A, compliance $\mathbf{K}$ is designed so that the relationship between $\mathbf{F}$ and $[\Delta x_A \ \Delta y_A]^T$ is given by $[\Delta x_A \ \Delta y_A]^T = \mathbf{K}[f_x \ f_y]^T$. The torque is generated by $[\tau_1 \ \tau_2]^T = \mathbf{G}_p[\Delta\theta_1 \ \Delta\theta_2]^T$ to provide the designed compliance $\mathbf{K}$. Calculate the matrix $\mathbf{G}_p$, when $\ell = 1$, $\theta_1 = \theta_2 = \pi/6$ and $\mathbf{K} = \begin{bmatrix} 0.01 & 0 \\ 0 & 0.02 \end{bmatrix}$.

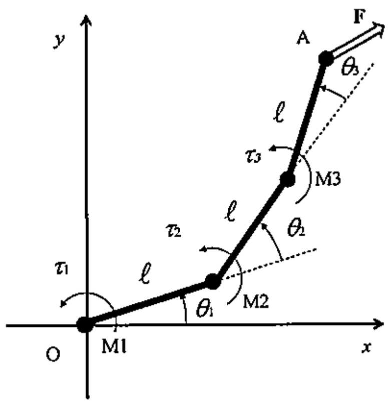

Fig. 3

P. 3. As shown in Fig. 3, a 3-link arm is located on the horizontal plane and the torques τ_1, τ_2, τ_3 are produced at the joint M1, M2 and M3, respectively. The tip position A is represented by $[x_A \ y_A]^T$, and three links of length ℓ rotate with angle $\theta_1, \theta_2, \theta_3$. Suppose that the arm is in static equilibrium. When force $\mathbf{F} = [f_x \ f_y]^T$ is applied to point A, compliance $\mathbf{K}$ is designed so that the relationship between $\mathbf{F}$ and the small displacement of point A is given by $[\Delta x_{\mathrm{A}}\ \Delta y_{\mathrm{A}}]^T = \mathbf{K}[f_x\ f_y]^T$. The torque is generated by $[\tau_1\ \tau_2\ \tau_3]^T = \mathbf{G}_{\mathrm{p}}[\Delta\theta_1\ \Delta\theta_2\ \Delta\theta_3]^T$ to provide the designed compliance $\mathbf{K}$. Derive $\mathbf{G}_{\mathrm{p}}$ by using compliance $\mathbf{K}$ and the Jacobian matrix $\mathbf{J}$ of $[x_{\mathrm{A}}\ y_{\mathrm{A}}]^T$ with respect to $[\theta_1\ \theta_2\ \theta_3]^T$, where $\mathbf{K}$ is a nonsingular matrix.

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Problem 3

P. 1. Answer the following questions.

(1) Self-information is a measure that indicates how the event is less likely when an event occurs. Show the definitional expression of self-information. You should add the description of symbols used.

(2) What is additivity of self-information? Describe it in about 3-5 lines using an example.

(3) Consider that 0,1,2 and 3 integer numbers appear randomly in a time-series data. Show information entropy when the probability of occurrence of each number is $p0$, $p1$, $p2$ and $p3$.

(4) There exists a coding technique that reduces the overall length by assigning a short code to the number of high occurrence probability. If $p0<p1<p2<p3$ for the $p0$, $p1$, $p2$ and $p3$ above, what code is appropriate to be assigned to each 0-3 value? Answer with when the length comes down.

P. 2. Answer the following questions about combinational logic circuits. Variables A, B, C take 0 or 1. ¬A means the negation of A, A+B means the logical sum of A, B and A·B means the logical product of A, B.

(1) Construct ¬A only using 2-input NAND gates.

(2) Construct A+B only using 2-input NAND gates. Also show the step-by-step design process.

(3) Construct ¬A·B+¬B·A only using 2-input NAND gates. Also show the step-by-step design process.

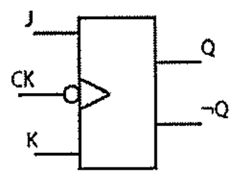
(4) Construct a circuit that has the truth table shown below only using 2-input NAND gates. Also show the step-by-step design process. This circuit is a part of a full-adder.

A	B	C	Output
0	0	0	0
0	0	1	1
0	1	0	1
0	1	1	0
1	0	0	1
1	0	1	0
1	1	0	0
1	1	1	1

P. 3. Answer the following questions about a flip-flop.

JK flip-flop is a circuit that transits between states as below.

J(t)	K(t)	Q(t+1)
0	0	Q(t)
0	1	0
1	0	1
1	1	¬Q(t)



(1) Construct an RS flip-flop using two 2-input NAND gates.

(2) Describe briefly an advantage of a JK flip-flop comparing with an RS flip-flop.

(3) Construct a JK flip-flop shown in the figure by only using 3-input NAND gates and 2-input NAND gates. You may assume that CK is 0 in sufficiently short period.

MEMO

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Problem 4

P. 1. Consider implementing an audio transmission system that distributes audio information via a network. Bandwidth of the network is 192kbps and transmission efficiency is 80%. 15% of the transmitted data is used for control information. Answer the following questions.

(1) How many seconds does it take to transmit digital audio data with a net of 10MB using this network? Answer round number of seconds with calculation process.

(2) The range of audio-frequency perceivable for human is between 20Hz and 20,000Hz. The sensitivity of human hearing is the highest at 1,000-3,500Hz, and almost all conversation is held among 200-8,000Hz. Give a few applications and answer an adequate sampling frequency with a reason for each application.

(3) The audio dynamic range is expressed in a decibel: $20\log_{10}(p/p_0)$ (p is sound pressure. p_0 is baseline of sound pressure). The typical dynamic range of cellular phones is 48dB, and the standard dynamic range of music CD is 96 dB. Answer an adequate quantization bit with a reason for each application. You may use that $20\log_{10}2$ is about 6.

(4) Assume that monaural sound is distributed in real time without any compression via this network. Based on (2) and (3), discuss a suitable application of this system with the optimal sampling frequency and quantization bit.

P. 2. Consider implementing compression and decompression program of a grayscale image with 256 gray levels, using the C language. Answer the following questions.

(1) Assume that an image (M pixels in width and N pixels in height) is converted into one-dimensional arrangement by scanning pixels sequentially from the left to the right and repeating from the top to the bottom. Then it is stored in the memory indicated by pointer `img`. Answer the value of pixel located in the i-th from the left and the j-th from the top, using `i`, `j`, `M`, `N`, and `img`. Note that `i` and `j` start from 0 respectively.

(2) Compression is performed by functions `getRLE` and `encode` shown in list 1. Explain the compression method concretely with the meaning of `run`, `code`, and `mx`, using numerical values, such as 0x80 and 0x7f. Suppose that the target file has already opened.

(3) Fill the blank of function `decode` shown in list 2 that reads compressed image data from the saved file by using function `encode` of (2) and expands it in the memory. Suppose that sufficient memory area for expanding image data has already allocated in the memory indicated by pointer `img`, and the target file has already opened. You may use the functions given in Table 1 in your program codes.

(4) By the compression method of (2), the size of the compressed file may become larger than that of uncompressed file in some cases. Explain the cases defining necessary variables by yourself and deriving the conditions.

Table 1

`int fputc(int c, FILE *stream)`	Write character "c" (converted to an 'unsigned char') to the output stream identified by "stream"
`int fgetc(FILE *stream)`	Get the next single character from the stream identified by "stream"
`int feof(FILE *stream)`	Tests whether or not the end of the file identified by "stream" has been reached, returns '0' if it has not yet been reached. If at end of file, the result is non-zero.

```
int getRLE(unsigned char *img, int x, int mx, int lim, int *run, unsigned char *code)
{
    int px;

    px = x; *run = 1; *code = img[px];
    px++;
    while(px<mx && *code==img[px] && *run<lim) {
        px++; (*run)++;
    }
    return px;
}

int encode(FILE *fp, unsigned char *img, int mx)
{
    int run;
    unsigned char code;
    int x;
    x=0;
    while(x<mx) {
        x=getRLE(img,x,mx,0x7f,&run,&code);
        if(run<2) {
            if(code<0x80){
                fputc((int)code,fp);
            } else {
                fputc(0x81,fp);
                fputc((int)code,fp);
            }
        } else {
            fputc(run|0x80,fp);
            fputc((int)code,fp);
        }
    }
    return 0;
}
```

list 1

```
int decode(FILE *fp, unsigned char *img)
{
    int i;
    int run, code;

    while(!feof(fp)) {
        code=fgetc(fp);
        
        
        
        
        
        
    }
    return 0;
}
```

list 2

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