UNIVERSITY OF MORATUWA
Faculty of Engineering
Department of Electronic & Telecommunication Engineering
B.Sc. Engineering
Level 4 – Semester 2 Examination
EN 4070 – ROBOTICS

Time Allowed: 2 hours September 2010

INSTRUCTIONS TO CANDIDATES

1. This paper contains **FOUR (04)** questions on **TWO (04)** pages.
2. This examination accounts for 80% of the module assessment. The marks assigned for each question and sections are included in square brackets.
3. This is an **OPEN** book examination. You are allowed to use **ONLY/ANY** written **AND/OR** printed material
4. Time allowed is 2 hours
5. Answer **ALL** questions

Question 1

{A} and {B_0} are two coincident frames as shown Figure Q1. Frame {B_0} undergoes two rotations and a translation as shown.

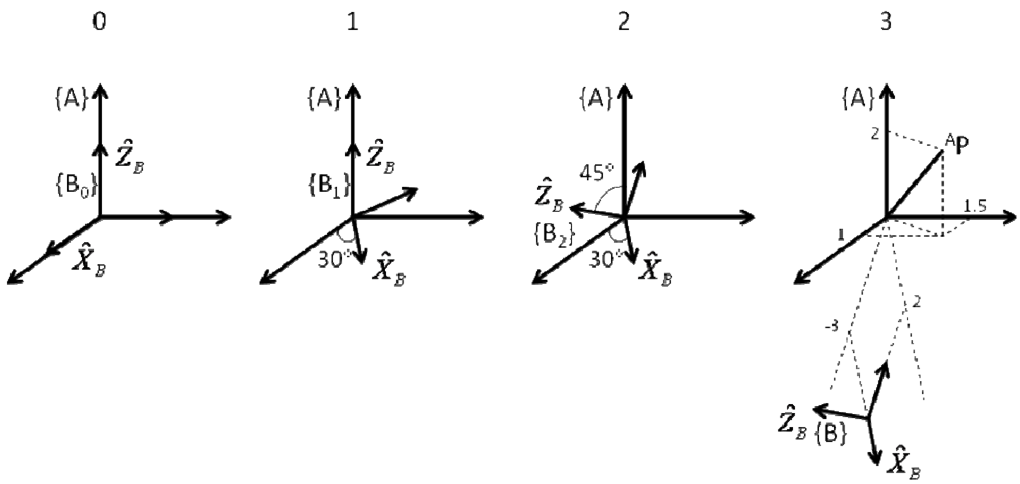

Figure. Q1: Frame rotation and translation

a) Calculate the rotation matrix ${}^{A}_{B}R$ [5]

b) Calculate the translation matrix ${}^{A}_{B}D$ [5]

c) Calculate the homogeneous transformation matrix ${}^{A}_{B}T$ [5]

d) Calculate ${}^{B}_{A}T$ without taking the inverse of ${}^{A}_{B}T$ [5]

e) Determine ${}^{B}P$ [5]

Question 2

A three link RRP manipulator is shown in Figure Q2

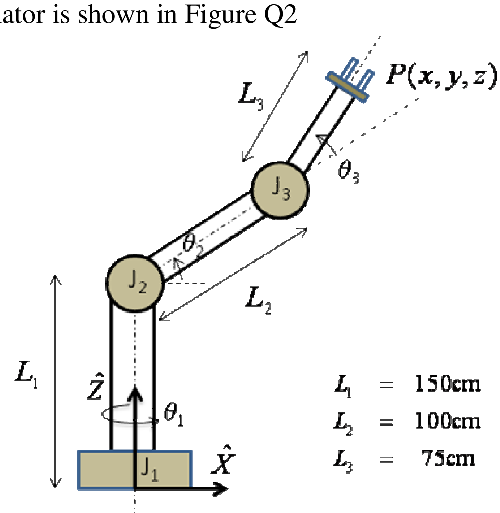

Figure. Q2: Three link RRR manipulator

a) Derive the three expressions $x = \mathbf{f}_x(\boldsymbol{\theta}),\ y = \mathbf{f}_y(\boldsymbol{\theta}),\ z = \mathbf{f}_z(\boldsymbol{\theta})$ of the forward kinematics $\mathbf{x} = \mathbf{f}(\boldsymbol{\theta})$ of the manipulator, where $\mathbf{x} = (x, y, z)^T$ is the Cartesian position and $\boldsymbol{\theta} = (\theta_1, \theta_2, \theta_3)^T$ is the joint configuration [10]

Continued …

b) Derive the Jacobian matrix $\mathbf{J}(\boldsymbol{\theta})$ of $\dot{\mathbf{x}} = J(\boldsymbol{\theta})\dot{\boldsymbol{\theta}}$. [5]

c) Figure out which joints most significantly contribute to the end-effector speed in $\hat{X}, \hat{Y}$, and $\hat{Z}$ directions, when the manipulator is in $\boldsymbol{\theta} = (30^0, 45^0, -60^0)^T$ configuration. [5]

d) In the above configuration, determine the end-effector speed and the direction of motion if joints are actuated with $\dot{\boldsymbol{\theta}} = (0.1, -0.3, 0.4)^T$ rad/s. [5]

Question 3

An Un-manned Aerial Vehicle (UAV) is to be fitted with an inertial measurement system to estimate the orientation of the vehicle. The inertial measurement system consists of a 3-axis accelerometer and a 3-axis gyroscope. An extract from the datasheet of the gyroscope sensors is given in Table Q1.

Table Q1: Gyroscope data

Symbol	Parameter	Test condition	Min.	Typ.(2)	Max.	Unit
FSA	Measurement range	4x OUT (amplified)		±300		°/s
FS		OUT (not amplified)		±1200		°/s
SoA	Sensitivity(3)	4x OUT (amplified)		3.33		mV/ °/s
So		OUT (not amplified)		0.83		mV/ °/s
SoDr	Sensitivity change vs temperature	Delta from 25°C		0.03		%/°C
Voff	Zero-rate level(3)			1.23		V
Vref	Reference voltage			1.23		V
OffDr	Zero-rate level change Vs temperature	Delta from 25°C		0.05		°/s/°C
NL	Non linearity	Best fit straight line		±1		% FS
BW	Bandwidth(4)			140		Hz
Rn	Rate noise density			0.035		°/s / $\sqrt{\text{Hz}}$
Top	Operating temperature range		-40		+85	°C

a) Use Z-Y-Z Euler angle representation for the UAV attitude. Show how you could obtain the angle set velocities (Z-Y-Z Euler rates) starting from gyroscope measurements. Assume an ideal gyroscope sensor [7]

(Note: Z-Y-Z Euler angle representation is defined as three rotations about moving axes in the following order: α around Z axis, β around Y axis, and γ around Z axis)

b) Refering to Table Q3, describe why the gyroscope sensors alone cannot provide an accurate estimate of the UAV attitude. [6]

c) Show how the accelerometer onboard the UAV can be used to measure the vehicle attitude. Clearly state any assumptions that you make. [6]

d) After conducting an experiment to determine the errors in both the gyroscope-based and the accelerometer-based attitude estimations, the followings were realized.

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(i) While the accelerometer based estimation is accurate in long term, it is not fast enough to reflect quick changes in actual UAV attitude

(ii) Gyroscopes have faster responses than accelerometers but the attitude estimation based on gyroscopes has a slowly varying error.

Using the above results, describe a simple method to fuse the two estimations together, in order to obtain a better estimate of the UAV attitude. [6]

Question 4

Stanford Scheinman Arm along with its kinematic model are shown in Figure Q4.

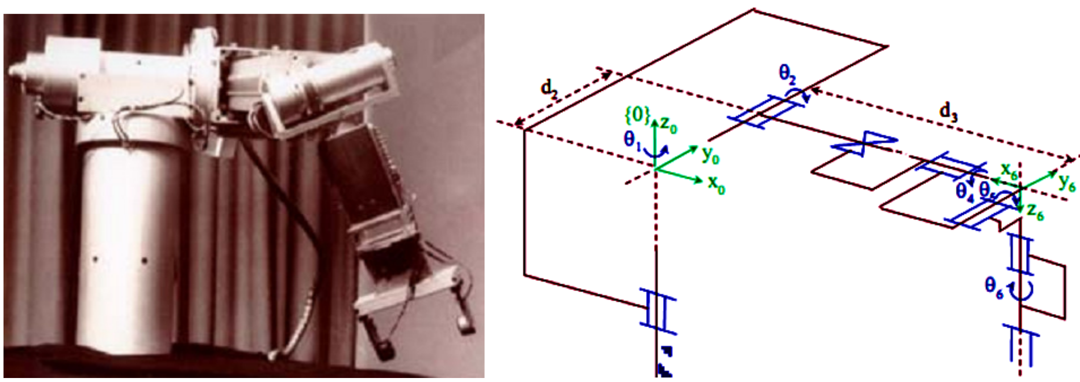

Figure Q4: Stanford Scheinman arm and its kinematic model

a) Describe the kinematic design of the robot arm emphasizing how it has been designed to allow convenient position and orientation control. (you may readily use kinematic equations o verify your answer) [6]

b) Write down the expressions for the following:

(i) Position of frame {2} with respect to frame {0}
(ii) Orientation of frame {4} with respect to frame {0}
(iii) Position of z-axis of frame {5} with respect to frame {0} [7]

c) Using forward kinematics and differential kinematics of the robot arm end-effector position $\mathbf{x}_p$, sketch an inverse Jacobian feedback control loop to make the end-effector follow a reference trajectory $\mathbf{x}_{ref}$ [6]

d) One of the joints of the robot arm with regard to the above feedback control loop has joint dynamics given by $\frac{12}{s^3+5s^2+2s}$. Calculate the required forward gain in order to increase the control bandwidth to 10 rad/s. [6]

 End of paper