Seat No	
Student Name	
Student ID	
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EXAM COVER SHEET

NOTE: DO NOT REMOVE this exam paper from the exam venue

EXAM DETAILS					
Course Code:	**MANU1417**				
Course Description:	**Advanced Robotics**				
Date of exam:	24/10/2016	**Start time of exam:**	1:45 PM	**Duration of exam:**	2hr 15min
Total number of pages (incl. this cover sheet)	5				

ALLOWABLE MATERIALS AND INSTRUCTIONS TO CANDIDATES

1. Write your full name and student number on each exam booklet together with the number of exam books used.
2. Students must not write, mark in any way any exam materials, read any other text other than the exam paper or do any calculations during reading time.
3. All mobile phones must be switched off and placed under your desk. You are in breach of exam conditions if it is on your person (ie. pocket).
4. This is an **OPEN BOOK** Exam.
5. Commence each question on a new page. Carry out the instructions on the front cover of the exam script book and the front of this exam paper.
6. Non text storing calculators are allowed.

Advanced Robotics – MANU 1417

Final Exam (Semester 2, Year 2016)

Question 1 (7 Marks)

Frame {B} is initially coincident with frame {A}. First, {B} is rotated about X_B by 30 degrees, and is subsequently rotated about Y_B by 45 degrees, followed by a rotation about Z_B by 15 degrees.

(a) Give the rotation matrix which accomplishes these 3 rotations in the given order. **Note**: All values in each step should be rounded to **4 decimal points**. (3 Marks)

(b) Calculate the Euler parameters for the above rotation matrix. **Note**: Do **NOT** calculate part (c) first and use the values to calculate answers for part (b). (2 Marks)

(c) Calculate the unit vector and the single angle of rotation, using the equivalent angle-axis representation, for the above rotation matrix. (2 Marks)

Question 2 (3 Marks)

The rotation matrix from A to B is:

$$ {}^{A}_{B}R = \begin{bmatrix} 0.933 & 0.067 & 0.354 \\ 0.067 & 0.933 & -0.354 \\ -0.354 & 0.354 & 0.866 \end{bmatrix} $$

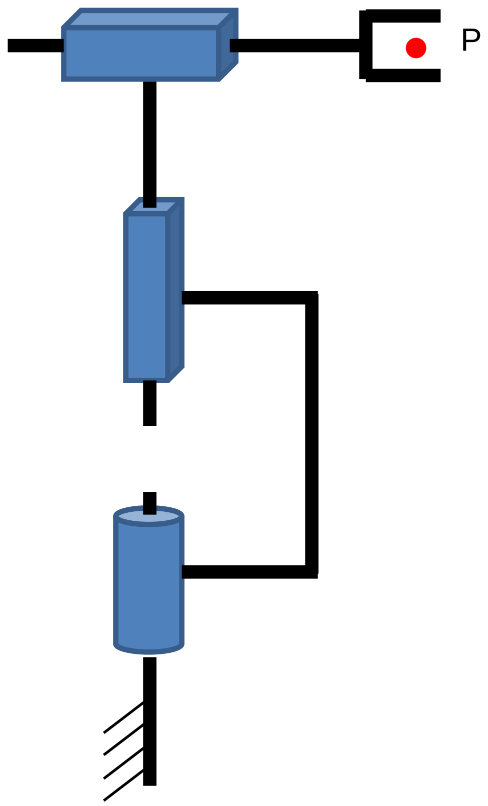
Also, the origin of frame {B} has the coordinate of $[5, 10, 2]^T$ when specified in frame {A}.

(a) Write down the homogenous transformation matrix ${}^{A}_{B}T$ (1 Mark).

(b) Calculate the inverse of the above homogenous transformation matrix (2 Marks).

Question 3 (11 Marks)

The kinematic structure of a 3-link <u>RPP</u> robot is shown in the following diagram.



(a) Derive the DH-Parameters of the manipulator, and tabulate them. You should provide some simple explanations (e.g. convention, definition) of how you get those parameters instead of just writing the final answer (4 Marks)

(b) Sketch the frames {0}, {1}, {2} and {3}. (2 Mark)

(c) Calculate the transformation matrices ${}^{0}_{1}T$, ${}^{1}_{2}T$, ${}^{2}_{3}T$ and ${}^{0}_{3}T$ (2 Marks).

(d) Calculate the linear Jacobian matrix for the manipulator. (2 Marks).

(e) Calculate the rotational Jacobian matrix for the manipulator. (1 Mark).

Question 4 (20 Marks)

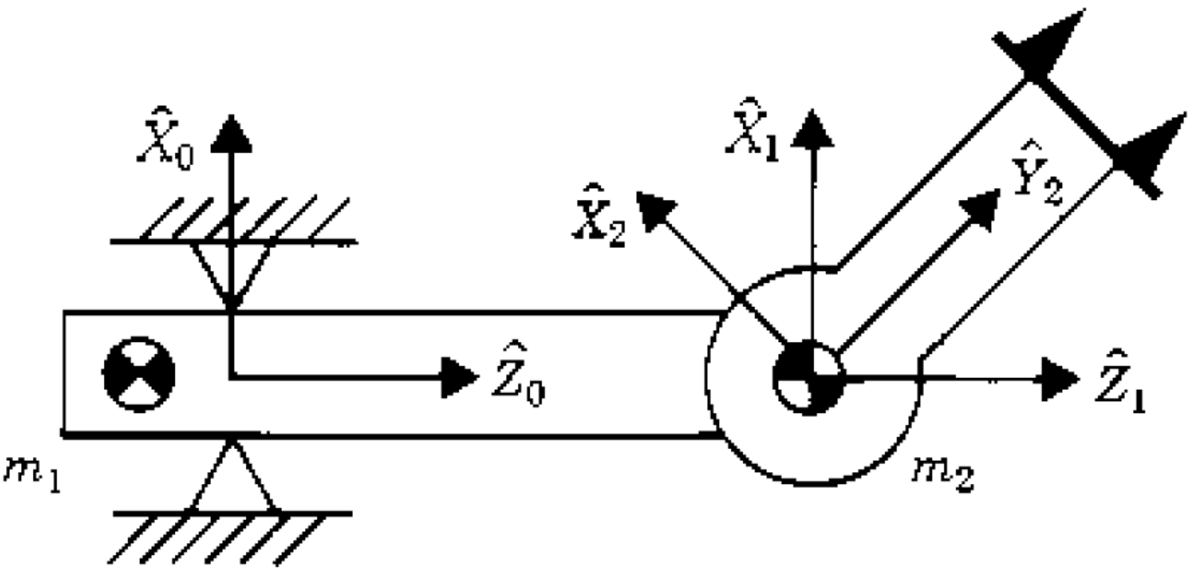
Consider the following PR Manipulator.

Friction is negligible, and gravity points in the negative X_0 direction.

The inertia tensor of the links are diagonal with moments Ixx1, Iyy1, Izz1 and Ixx2, Iyy2, Izz2.

The centers of mass for each link are given by:

$$ {}^{1}P_{C_1} = \begin{bmatrix} 0 \\ 0 \\ -l_1 \end{bmatrix} \qquad {}^{2}P_{C_2} = \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix} $$



(a) Tabulate the DH-parameters of the manipulator. (Hint: The axes are already labelled, and thus the parameters can be read-off easily. Alternatively, you may use the definitions and conventions for link and joint parameters to do this). (2 Marks)

(b) Calculate all the required quantities (velocities, accelerations, forces / moments) for the outward iterations of the iterative Newton-Euler dynamic algorithm. (8 Marks)

(c) Calculate all the required quantities (forces, torques) for the inward iterations of the iterative Newton-Euler dynamic algorithm. (6 Marks)

(d) Write down the dynamic equations for the manipulator. The answer should be given in the “general structure” involving mass matrix, Coriolis and centrifugal vector, as well as gravity vector. (4 Marks)

Question 5 (9 Marks)

Consider a robotic system described by:

$$M(q)\ddot{q} + V(q,\dot{q}) + G(q) = \tau$$

(a) Design a nonlinear controller such that the manipulator has constant stiffness and damping throughout its workspace. (3 Marks).

(b) State one advantage and one disadvantage of your design (2 Marks).

(c) Assume you want to control the robot such that its joints follow certain trajectories. For joint 1, the constraints are:

$$\theta_{10} = 10^0$$
$$\theta_{1tf} = 50^0$$

All start and ending velocities and accelerations are zero.
The end time is 2 seconds.

Calculate the parameters of a quintic polynomial which can satisfy all the given constraints (4 Marks).