# IN3140/IN4140 - Mandatory Assignment 1

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Due: Sunday, March 3rd 23:59 (24h)

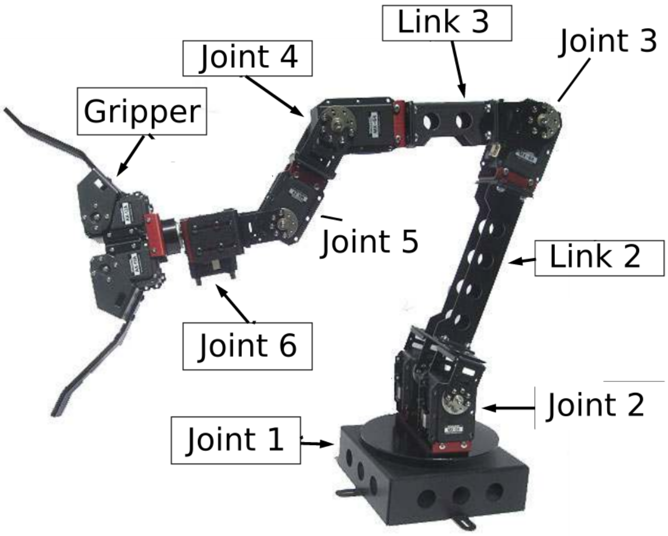


Figure 1: The CrustCrawler robot

## Introduction

Figure 1 displays the CrustCrawler robot that we will work with in the mandatory assignments in IN3140/IN4140. The CrustCrawler is a six-axis robotic arm with an optional gripper attachment. The base of the arm is a turntable (*Joint 1*) which allows the arm to turn around its own axis. The arm itself is composed of six servo motors to allow for multiple degrees of freedom. Attached to the turntable is a double actuator joint (*Joint 2*), composed of two servos. *Link 2* connects *Joint 2* and *Joint 3*. We then have *Link 3*, connected to *Joint 4*. Connected directly to *Joint 4* is another servo, *Joint 5*, which is parallel to *Joint 4*, *Joint 3* and *Joint 2*. Lastly, the axis of rotation for *Joint 6* is perpendicular to the axis of rotation of *Joint 5*. The optional gripper is attached to *Joint 6*.

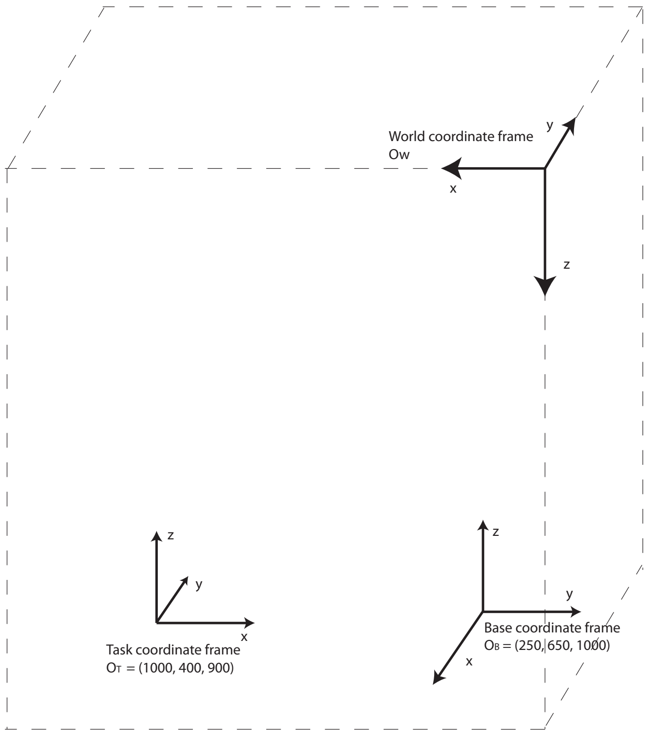


Figure 2: Coordinate frames (see also figure 4)

## Task 1 - Transformations - (10%)

Figure 2 shows three coordinate frames and the direction of the axes. We name the coordinate frames *World coordinate frame* {W}, *Base coordinate frame* {B} and *Task coordinate frame* {T}.

Origin of coordinate frame {B}, relative to {W}, is located at position

$$O_B = (250, 650, 1000) \tag{1}$$

Origin of coordinate frame {T}, again relative to {W}, is located at position

$$O_T = (1000, 400, 900) \tag{2}$$

- The axes $Z_W$, $Z_B$ and $Z_T$ are parallel to each other
- The axes $X_W$, $Y_B$ and $X_T$ are parallel to each other
- The axes $Y_W$, $X_B$ and $Y_T$ are parallel to each other

**Task** Find $T_T^B$ (the transformation matrix expressing the position and orientation of {T} with respect to {B}, said in other words; a vector that goes from {B} and ends up in {T}).

**NOTE** *Show your solution by setting up the necessary expressions, formulas and calculations clearly.*

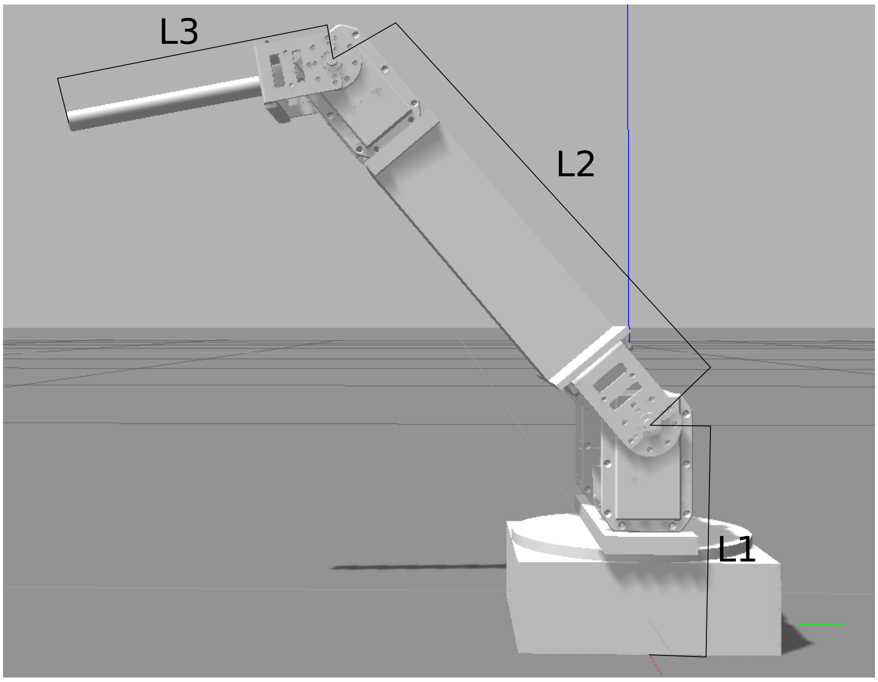


Figure 3: Simplified robot model in Gazebo

## Task 2 - Forward Kinematics I - (30%)

To simplify the exercise we will now look at a restricted model of the CrustCrawler robot. We remove joints [4, 5, 6] so that the CrustCrawler resembles the arm shown in figure 3. This simplified version only has three joints and three links.

**a) 5%** Sketch the workspace of the robot (a quick 3D drawing from top and side view is sufficient).

**b) 7.5%** Draw a simple 3D illustration of the robot, showing the coordinate frames and the Denavit-Hartenberg parameters.
**Use the standard for symbolic representation of 3D robot joints, found in Chapter 1.1.1 in the course book. You can see an example of a correct 3D representation of a robot on page 85 in the course book, figure 3.7.**
Explain (briefly) your choice of origin and rotation axis.
Show the DH-parameters in a table.

**c) 17.5%** Calculate the forward kinematics for this robot. Your answer should be an algebraic transformation matrix $T_t^B$ denoting the transformation of the tool coordinate frame {t} located at the tip of the arm, with respect to the base coordinate frame {B}. This transformation matrix is a function of the three joint variables.

**NOTE** *The functions simplify() and subs() can be useful MATLAB tools for task 2c. However, forward kinematics must be calculated by hand on the exam, so we strongly advise you to familiarize yourself with this process.*

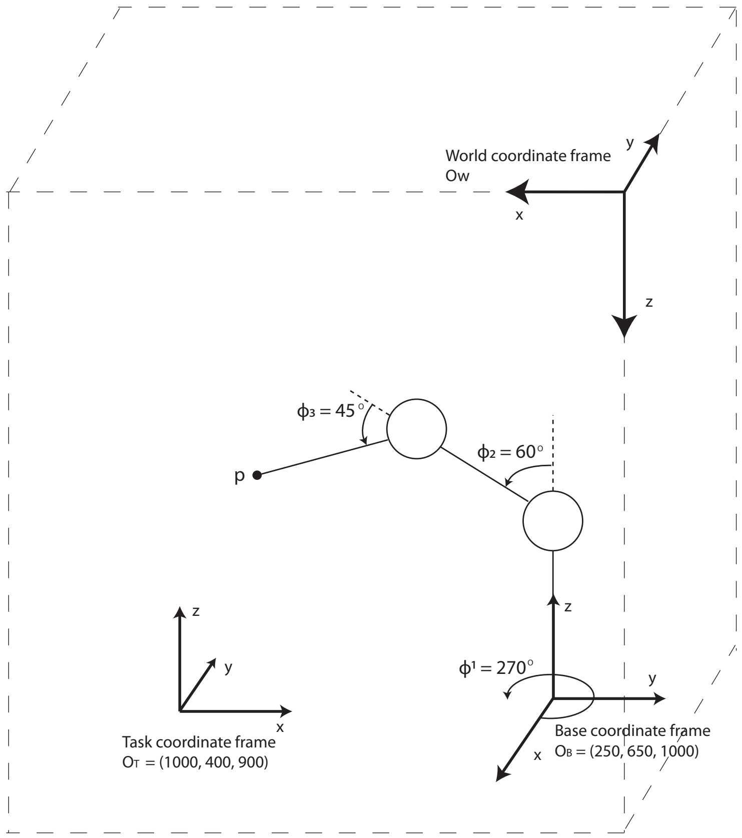


Figure 4: Robot with respect to World and Task frame

# Task 3 - Forward Kinematics II - (15%)

Point $p$ is located at the tip of the robot (the last link). Adjust the robot as displayed in Figure 4, where $\phi_1 = 270°, \phi_2 = 60°, \phi_3 = 45°$.

These ($\phi$) angles are of course not to be used directly, **you have to figure out the correct $\theta$-angles for your robot configuration**, with respect to how you have used the DH-convention to describe the robot. Link lengths in the figure are not proportional to the real robot.

Use the following dimensions in your calculation:

- $L1 = 100.9mm$
- $L2 = 222.1mm$
- $L3 = 136.2mm$

**Task** Find $p^T$, the coordinates of point $p$ given in task coordinate frame {T}.

**HINT** *Use your calculations from task 1 and 2c to find the answer.*

## Task 4 - Inverse Kinematics - (25%)

**a) 2.5%** Name and briefly describe the two most common methods of deriving inverse kinematics. State which of the methods you are going to use to solve subtask b).

**b) 20%** Derive the inverse kinematics equations for the simplified robot and show the different steps.

**c) 2.5%** How many solutions exist for the joint angles given an arbitrary position of the tip of link 3? We do not have any physical restriction on $\theta_1$, and you can also assume that there are no physical restrictions on $\theta_2$, other than the angles that would make L2 and L1 completely overlap.

**NOTE** *We advise students to solve subtask 4b) by hand. Similar tasks will be given on the exam, and an understanding of how to calculate the inverse kinematics by hand is very valuable!*

## Task 5 - Forward and inverse kinematics - (20%)

Implement the forward and inverse kinematics as function in Python.

The robot is displayed in figure 3. Once more, the dimensions in millimeters are:

- L1 = 100.9
- L2 = 222.1
- L3 = 136.2

**a) 5%** The forward kinematics function takes a list of joint angles as input and returns the corresponding cartesian coordinates for the tip of the arm as output:

```
def forward(joint_angles):
"""returns cart_cord"""
```

**b) 5%** The inverse kinematics function takes the cartesian position of the tip of the arm as input, and gives the corresponding joint configurations as output:

```
def inverse(cart_cord):
"""returns joint_angles"""
```

**c) 5%** Use the functions to show how you can verify that the inverse and forward kinematics are correctly derived. Hint: Use a function like round() in Python and at least 4 decimals accuracy.

**d) 5%** The TCP (Tool Center Point) is located at [x,y,z]=[0;-323.9033;176.6988] in the Base coordinate frame. Calculate all possible sets of solutions of the joint variables according to your DH setup. The answers must be in degrees with maximum four decimals.

# Task 6 - Kinematics in Gazebo - (Optional)

Use your functions to control the position of the 3-link Crustcrawler, in Gazebo.

*More info on this after ROS lectures in week 8*

**CHALLENGE:** Rewrite your kinematics to work for the Crustcrawler with a pen offset on the tip.

# Task 7 - Kinematics - (Optional)

Generally speaking about robots, what does the kinematics describe?

**REQUIREMENTS:**
**Obtain a total score of at least 50%.**
Each student must hand in their own assignment, and you are required to have read the following declaration about student submissions at the department of informatics: https://www.uio.no/studier/eksamen/obligatoriske-aktiviteter/mn-ifi-obliger-retningslinjer.html

In case you are unable to read the declaration due to the limited understanding of the language or for any other reason, please contact any of the group teachers for clarification.

**IMPORTANT! Name the pdf file;**

**"in3140_oblig1_*your_username.pdf*"**

Submit your assignment at https://devilry.ifi.uio.no.
Your submission must include:

1.) A pdf-document with answers to the questions.

2.) The two illustrations asked for in question 2a and 2b

3.) **A README.txt containing a short reflection on the assignment**; what was difficult, what was easy, was there anything you could have done better?

Wherever you use MATLAB, Python or other tools for computing an answer, your solution and approach must be illustrated and explained thoroughly in the pdf file. The files containing the code must also be delivered and named;

**"in3140_oblig1_taskXX_*your_username.py .m .cpp etc*"**

You are required to use Python programming language to solve task 5. The same applies to task 6, should you make an attempt. For the remaining tasks, you are free to use whatever programming languages and tools you are familiar with, but we strongly recommend solving them by hand.

***Deadline: Sunday, March 3rd 23:59 (24h)***

You can use the slack channel *assignment 1* for general questions about the assignment, and the channels *forward_kinematics* and *inverse_kinematics* for discussion. Slack team domain is; https://inf34804380robotics.slack.com
Do not hesitate to contact us if you have any further questions.

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