<u>Homework #2</u>

Robot Dynamics, Fall 2019

<u>Part A:</u> Due Friday, Sept 20 by 11:59pm EST

<u>Part B:</u> Due Friday, Sept 27 by 11:59pm EST

Submit the assignment itself as a single published Matlab PDF output, along with any code or supplemental material in a zip file through Canvas.
One submission (pdf + zip file) for Part A & a separate submission for Part B.

In HW #2 you will solve for the forward kinematics of the <u>ABB IRB 120</u> 6-DOF robotic manipulator. This assignment is intended to give you real-world experience in determining kinematics of a typical commercially available industrial robot. *This is the same robot we have in the WPI AIM Lab that some of you may use for your projects.* The robot configuration is shown at the end of this document, and additional information may be found in the provided product specification. ABB Robotics Studio is used to simulate the robot – this will help to get a feel for how it moves and enable you to test out your solutions (Robot Studio s*etup instructions provided at the end of the assignment*).

Please complete the following steps <u>showing and clearly documenting all work and intermediate steps</u>. In completing this assignment, you should use Matlab with the Symbolic Toolbox to prepare your solutions where appropriate. *If any parameters are not defined, clearly state any assumptions used in your solution.*

*Be sure to include all code, clearly annotated with what you are doing and labeling the solutions. Clear presentation is critical to receive partial credit. <u>It is expected to prepare the assignment in Matlab **and use the Publish function** to generate your submission as a single pdf file per Part.</u> Using the publishing feature, you can embed drawings and figures including scanned hand drawings and screen shots.*

***Please read through this complete assignment worksheet before starting. There is important information in the appendix at the end on the robot configuration and how to set up and use the simulator.*

<u>Part A – Solving for Kinematics:</u>

1. [10pts] On a line drawing of the robot (such as from the figure below of the manual), define and label coordinate frames for the base, each link, and the tip. You should do this <u>using the D-H convention from this class</u>. Clearly show the location of the origin and the direction for each axis of each frame that you define. Be sure to use the axis numbering, base & tool frame, and rotation direction conventions provided for the robot and matching that of the simulation. *As previously noted, you are expected to use the D-H convention presented in this class – some other references may have variants in indexing that can cause confusion so be careful with outside references & examples.*

2. [10 pts] Determine the D-H parameters for the robot and show a clearly labeled table. Be sure to include units, identify the joint variables, and check your joint directions. Generate Matlab variables for each of the 4 parameters as nx1 vectors.

3. [10 pts] Determine the frame transformations from one link to the next as homogeneous transformations matrices (i.e. T^{0}_{1} , T^{n-1}_{n}).

    a. Create a Matlab function that takes a set of DH parameters (each of the 4 parameters as an nx1 vector) for a link and returns a 4x4 homogeneous transformation matrix <u>using the following syntax</u>.

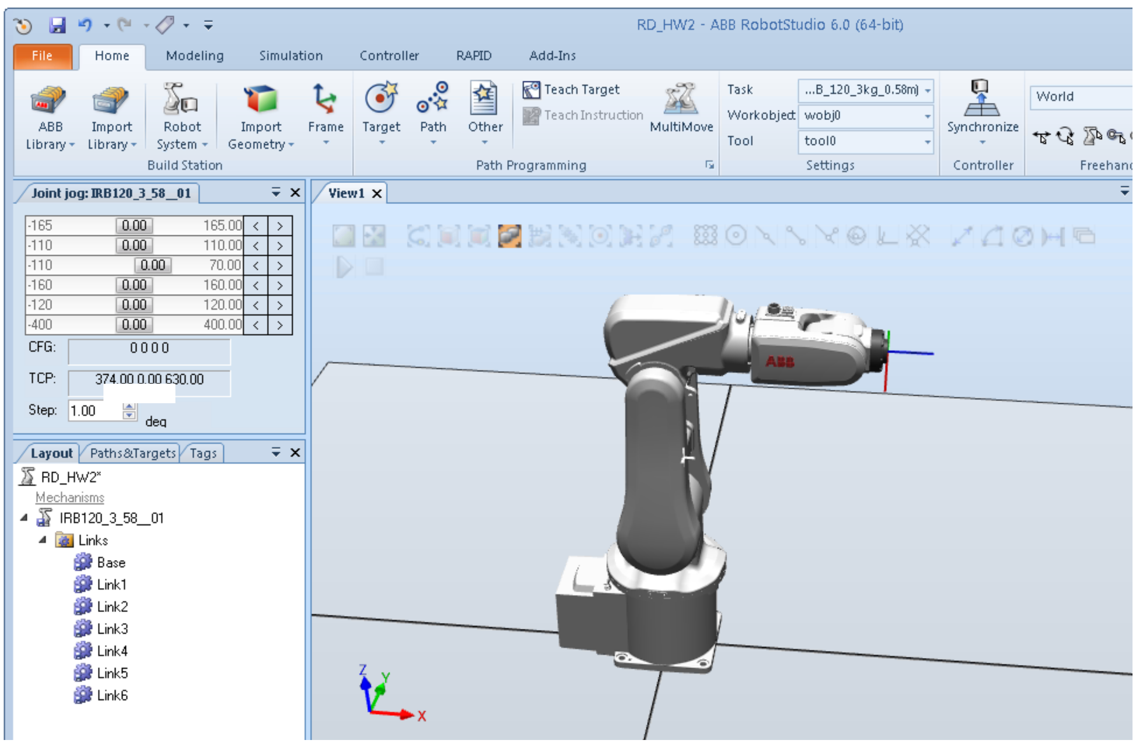
    ```
    T = dhparam2matrix(theta, d, a, alpha)
    ```

    b. Write a loop that goes through all n links to generate the respective corresponding transformation matrix.

    c. Show the symbolic 4x4 SE(3) transformation matrices corresponding to each of the intermediate transformations.

4. [5 pts] Solve for the composite transformation representing the forward kinematics from base to tip ($T^0{}_n$). Be sure to show your work and simplify the solution as much as possible. *This will be a large symbolic 4x4 matrix.*

5. [5 pts] Plug into the answer for Problem 4 the home/zero joint configuration [0°, 0°, 0°, 0°, 0°, 0°] as shown in the figure below. Show the numeric 4x4 homogeneous transformation matrix representing the 6-DOF pose tip frame with respect to the base frame. *Check that the rotation matrix and the x,y,z offset directions match what you would have expected by inspection of the figure below.*



Configuration for Question 5

(Home/Zero Configuration of IRB 120 Robot)

6. [10 pts] For the following joint configuration [-45°, 30°, -30°, -30°, -45°, 180°], determine the forward kinematics of the end effector (configuration shown below). T*hese values represent the angles with respect to the previous link as we typically use in class*.

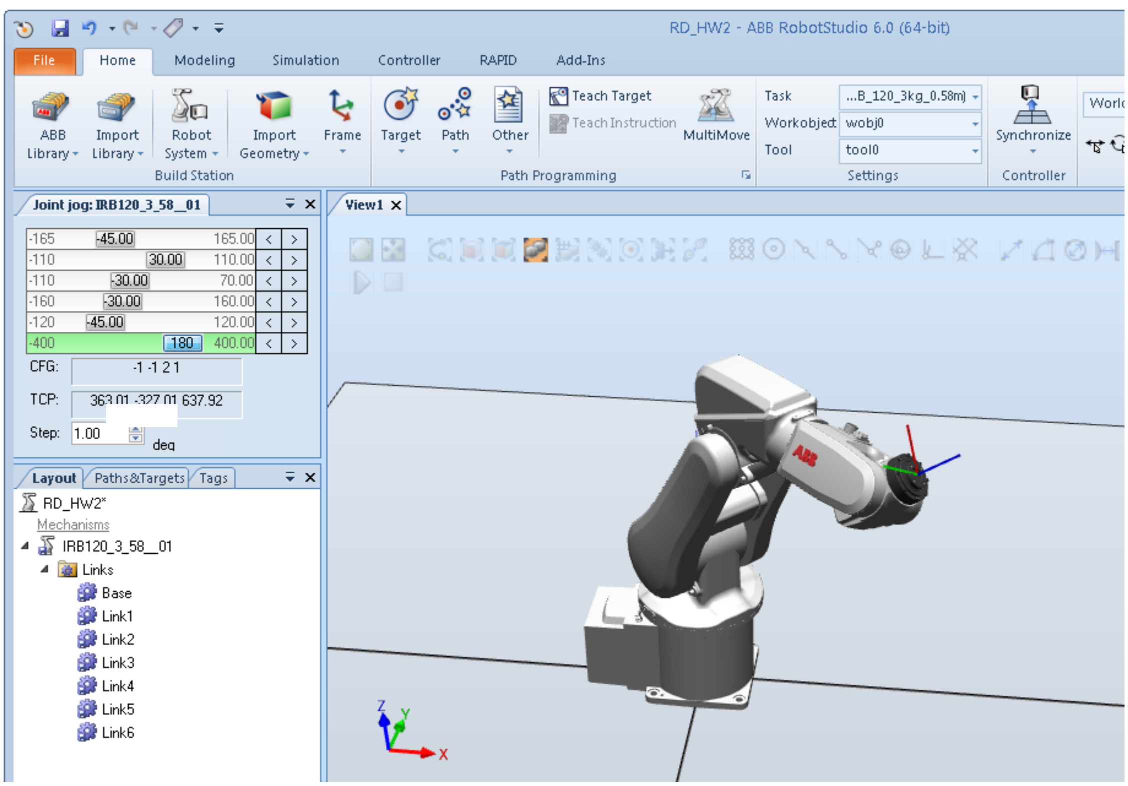
    a. Determine the numeric 4x4 homogeneous transformation matrix representing the tool's pose (tip frame) with respect to the base frame for this joint configuration.

    b. Clearly state:

        i. The Cartesian position of the robot tip, including units

        ii. The unit vector representing the approach vector of the robot in this configuration

This configuration is shown to help visualize how the joints move. However, you should play with the motions (Joint Jog) to get a feel for how it moves.



Configuration for Question 6

Part B – Simulating the Manipulator:

7. [15 pts] Develop a Matlab function with a model of the arm that will solve the forward kinematics and draw each link (solid line) and joint (solid point) in a 3D plot based upon an input vector of the joint angle configuration. *A barebones example is shown in the figure below, but feel free to make nicer looking models.*

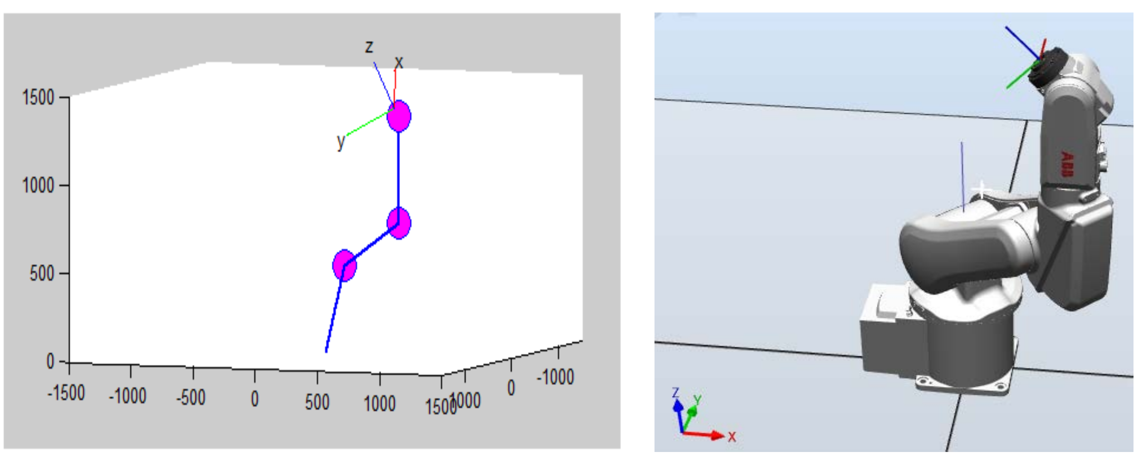
   It should output, and show on the figure, the position and orientation of the end effector for the given configuration as a 4x4 homogeneous transformation matrix (T) with respect to the base frame.

   The function should be of the following form with `qn` in degrees, T as a 4x4 transformation matrix with the position represented in *mm*:

   ```
   T = plotarm(q1, q2, q3, q4, q5, q6)
   ```

   Extra Credit [10 pts]: Replace the stick model in Part 7 with imported 3D CAD data and animate the 3D model of the robot. You may need to open in Solidworks, define the origins as used in your model, and export STL files.

   You can download the CAD models from ABB for this robot here: http://new.abb.com/products/robotics/industrial-robots/irb-120/irb-120-cad



Example Stick and 3D Models for Question 7

This part of the assignment will be based on the configuration of a simulated version of the ABB IRB 120 6-DOF robotic manipulator robot. <u>You are to arbitrarily position the robot in five configurations of your choosing (must be unique, each axis must be moved in at least one of the selected configurations, and at least two axes must have non-zero motions in each selected configuration)</u>. For each of the 5 selected configurations you are to collect screen captures of the robot configuration as well as the joint space (6 joint angles) and task space (tip position and orientation in World coordinates) information and include with your solution embedded in the Published Matlab output.

8. [35 pts] For each of your unique selected Configurations #1 - #5, plug the joint space positions (q_1-q_6 from the simulator) into your forward kinematics calculation from Question 4 and numerically calculate the 6-DOF frame of the robot tip with respect to the base coordinate frame (being sure to include units). Use the Matlab function in Question 7 to plot the 3D model of the configuration.

   Show side-by-side from a similar view the Matlab 3D stick model and the ABB simulator model.

   Compare your numerical solution with actual 6-DOF frame reported by the ABB simulator and explain any deviations.

ROBOT CONFIGURATION

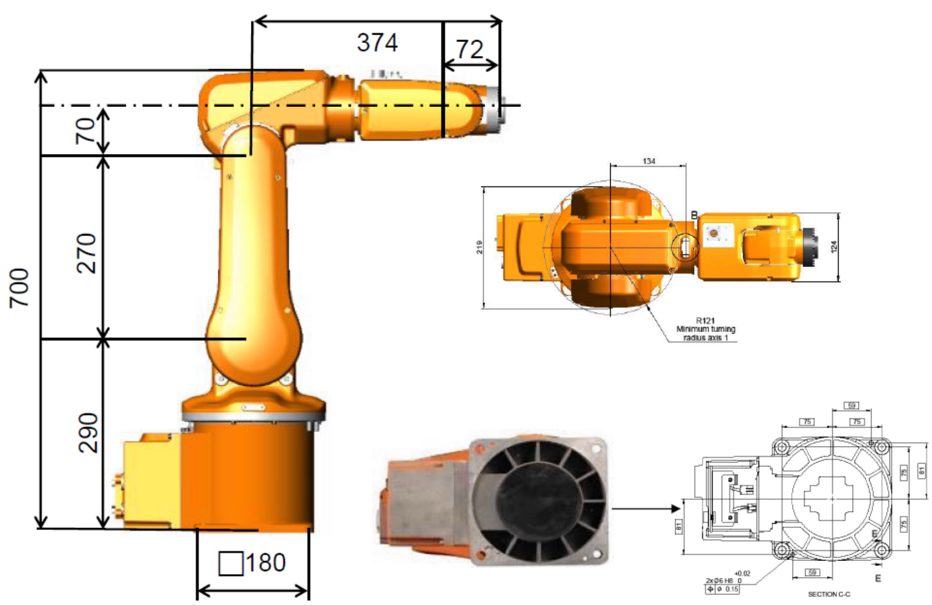
The following are from the 'ABB_IRB120_SpecSheet.pdf' and 'IRB120_ProductPresentation.pdf' documents posted on Canvas.

Additional information from the manufacturer can be found at: [*http://new.abb.com/products/robotics/industrial-robots/irb-120*](http://new.abb.com/products/robotics/industrial-robots/irb-120)

Robot Axis Numbering

	Range	Max speed (T)
Axis 1 Rotation	**+165° to -165 °**	250 °/s
Axis 2 Arm	**+110° to -110 °**	250 °/s
Axis 3 Arm	+70° to **-110** °	250 °/s
Axis 4 Wrist	+160° to -160 °	320 °/s (420 °/s)
Axis 5 Bend	**+120° to -120 °**	320 °/s (590 °/s)
Axis 6 Turn	+400° to -400 °	420 °/s (600 °/s)

Robot Dimensions (in mm)

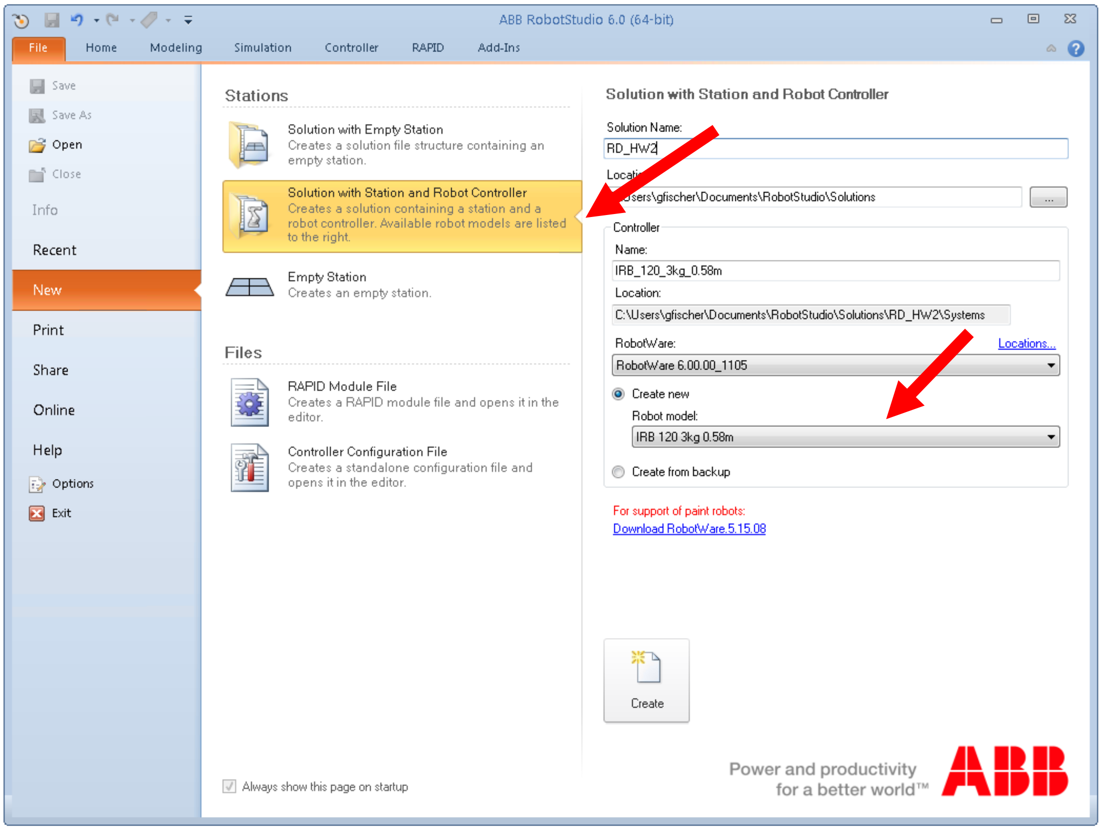


Using Robot Studio

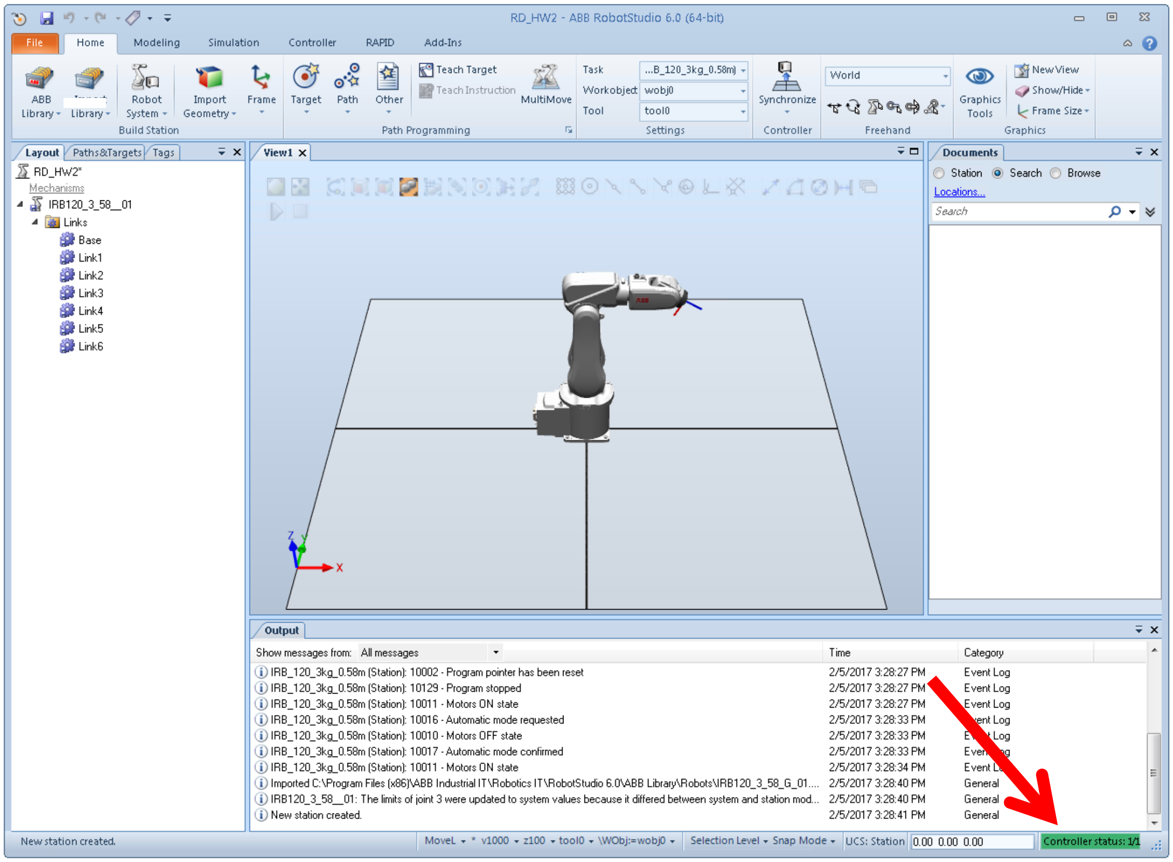
- Download and install the complete latest version of RobotStudio with RoboWare (Latest version looks to be 2019.2) at: http://new.abb.com/products/robotics/robotstudio/downloads

- It will run in a trial mode without a license (which is fine for our needs in this class), or you can point the installation wizard to the WPI license server which is located at: 130.215.33.84 *(you will need to use VPN or be on-campus for this to work)*

- Create a new robot workcell with the IRB 120 robot in an otherwise empty workcell using the configuration shown below. The robot base frame should be aligned with and coincident with World coordinates. *Be sure to select "Solution with Station and Controller" and the same "IRB 120 3kg 0.58m" robot as shown with arrows below.*

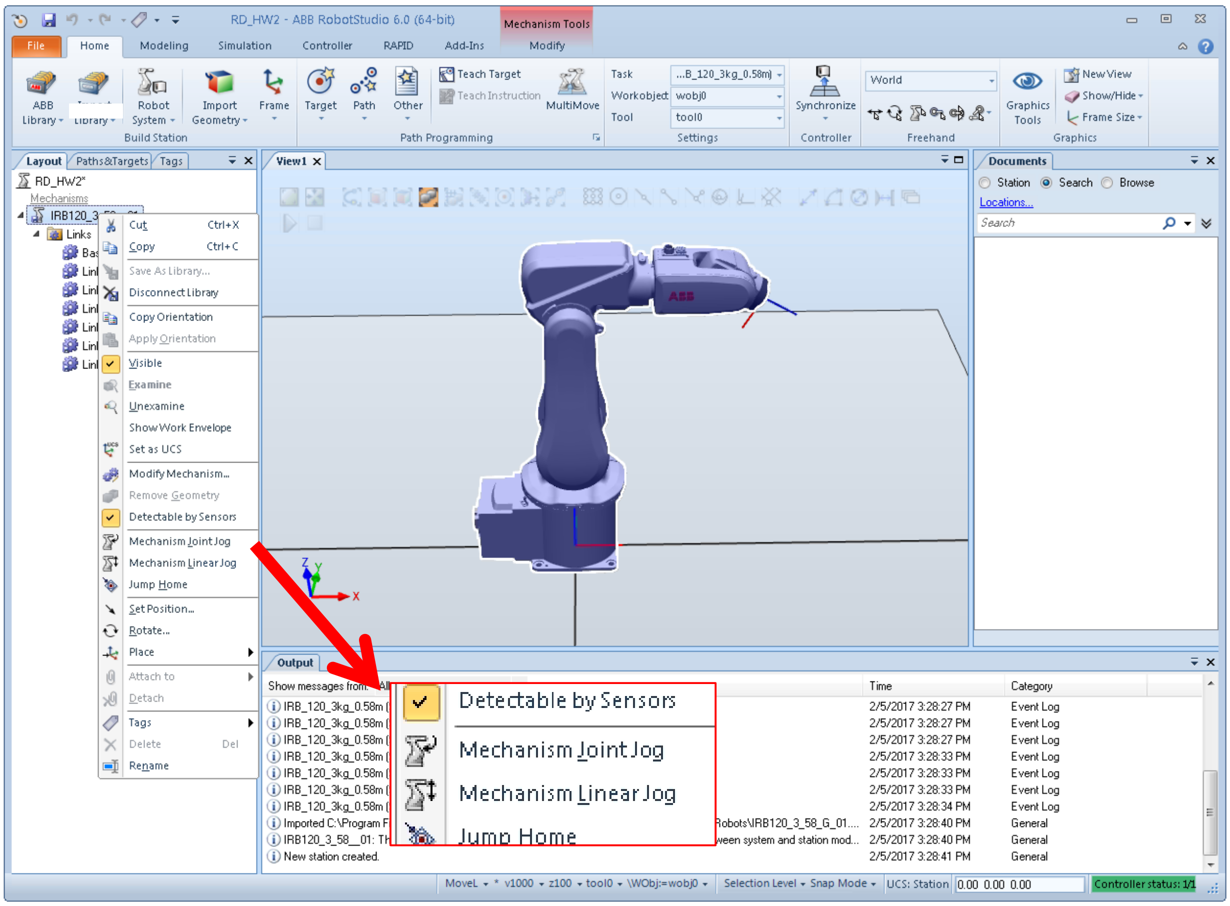


- The system will start up and then show the robot. *Be sure that you see a green box in the bottom-right of the screen (as shown with arrow). It may take some for the virtual controller to “boot up”. If you do not get a green box, you will not be able to use the inverse kinematics simulator to check your work since it is calculated as part of the simulated controller.*

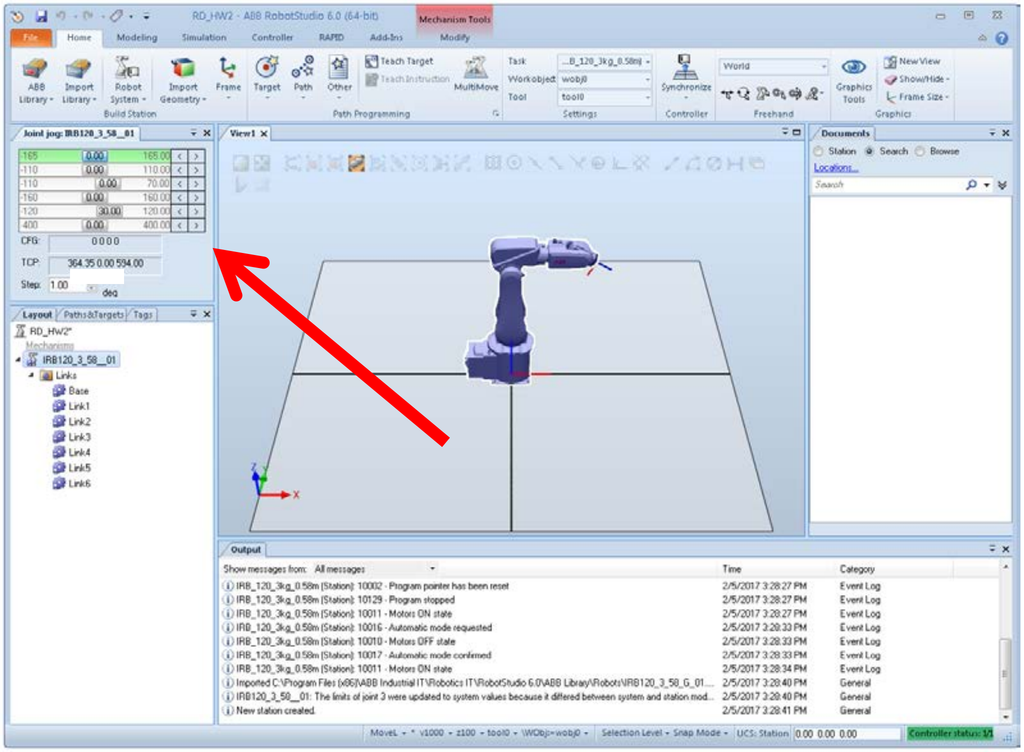

RD_HW2 - ABB RobotStudio 6.0 (64-bit)
File
Home
Modeling
Simulation
Controller
RAPID
Add-Ins
ABB Library
Robot System
Import Geometry
Frame
Target
Path
Other
Teach Target
Teach Instruction
MultiMove
Build Station
Path Programming
Task
Workobject
Tool
wobj0
tool0
Settings
Synchronize
Controller
World
Freehand
Graphics Tools
New View
Show/Hide
Frame Size
Graphics
Layout
Paths&Targets
Tags
RD_HW2*
Mechanisms
IRB120_3_58__01
Links
Base
Link1
Link2
Link3
Link4
Link5
Link6
View1
Documents
Station
Search
Browse
Locations...
Output
Show messages from: All messages
Time
Category
IRB_120_3kg_0.58m (Station): 10002 - Program pointer has been reset 2/5/2017 3:28:27 PM Event Log
IRB_120_3kg_0.58m (Station): 10129 - Program stopped 2/5/2017 3:28:27 PM Event Log
IRB_120_3kg_0.58m (Station): 10011 - Motors ON state 2/5/2017 3:28:27 PM Event Log
IRB_120_3kg_0.58m (Station): 10016 - Automatic mode requested 2/5/2017 3:28:33 PM
IRB_120_3kg_0.58m (Station): 10010 - Motors OFF state 2/5/2017 3:28:33 PM
IRB_120_3kg_0.58m (Station): 10017 - Automatic mode confirmed 2/5/2017 3:28:33 PM
IRB_120_3kg_0.58m (Station): 10011 - Motors ON state 2/5/2017 3:28:34 PM
Imported C:\Program Files (x86)\ABB Industrial IT\Robotics IT\RobotStudio 6.0\ABB Library\Robots\IRB120_3_58_G_01.... 2/5/2017 3:28:40 PM General
IRB120_3_58__01: The limits of joint 3 were updated to system values because it differed between system and station mod... 2/5/2017 3:28:40 PM General
New station created. 2/5/2017 3:28:41 PM General
New station created.
MoveL
v1000
z100
tool0
\WObj:=wobj0
Selection Level
Snap Mode
UCS: Station
0.00 0.00 0.00
Controller status: 1/1

- To move the robot in joint space and see the robot joint angles, right click on the IRB120_3_58__01, expand Links, and select “Mechanism Joint Jog” as shown below.

- To move the robot in task space and see the robot’s 6-DOF task space pose, right click on the IRB120_3_58__012, expand Links, and select “Mechanism Linear Jog”.



Joint Space Mode:



Task Space (Linear) Mode: