Small project for the Robotics course 2018-2019

Bogdan M. Maris, PhD

Temporary Assistant Professor

E-mail bogdan.maris@univr.it

Premise

- The ‘small’ project is mandatory to access the theory exam
- In alternative the student can chose a more complex project (to be defined with the coordinator of the course)
- The time to realize the project is between 3-9 hours.
- The work will be organized in teams of 2-4 students (depending on the total number of students)
- There is no grade (‘voto’)
- The hardware will be provided during the laboratory hours or upon agreement with the lab tutor.
- All the students that decide for the ‘small project’ must send a mail to bogdan.maris@univr.it until 10-th of November 2018

Goals of the image-guided therapy and medical robotics tutorial

- To demonstrate the typical steps of an image-guided therapy (IGT) or medical robotics procedure.
- To learn in a hands-on manner using a LEGO Mindstorms EV3, a LEGO phantom and sophisticated medical image processing and IGT software (3D Slicer).
- The example procedure that we will use to do this is a needle biopsy.
- To learn about the registration step in IGT and medical robotics.
- To learn about the following steps in IGT and medical robotics in a hands-on manner:
  - Imaging
  - Preoperative planning
  - Targeting and tracking
  - Navigation

The example procedure that we will use to do this is a needle biopsy.

Precautions

- The project is inspired by the tutorial at the link:
  - https://www.slicer.org/wiki/Slicer3:_Image_Guided_Therapy_(IGT)

But:

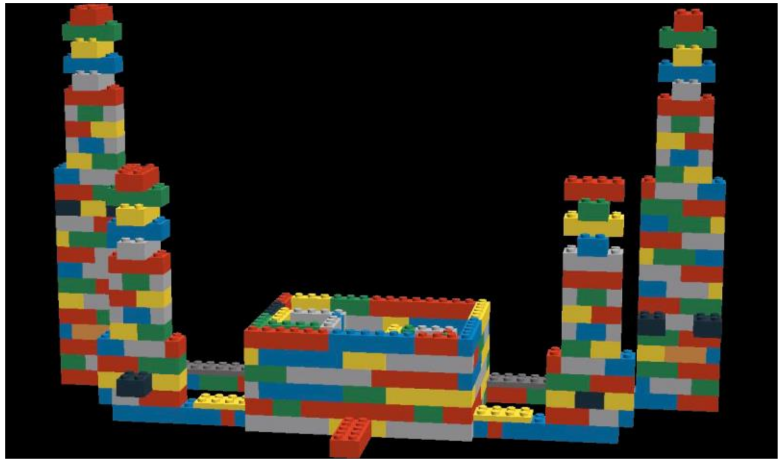
- Different robot kit (newer)
- Updated version of 3DSlicer
- Different plug-in, provided on the internet page of the Robotics class:

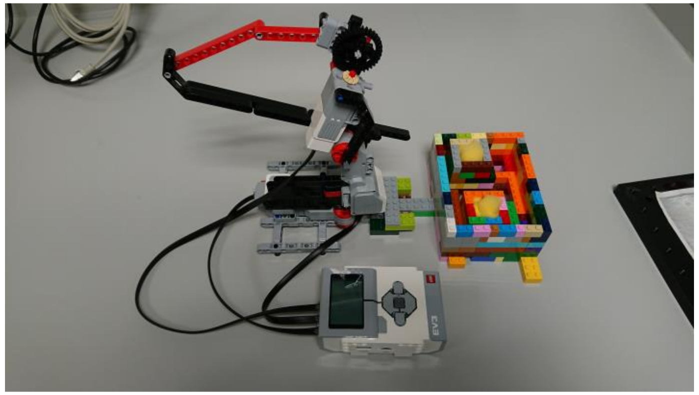
http://www.di.univr.it/?ent=oi&aa=2018%2F2019&codiceCs=S71&codins=10877&cs=417&discr=&discrCd=&lang=en

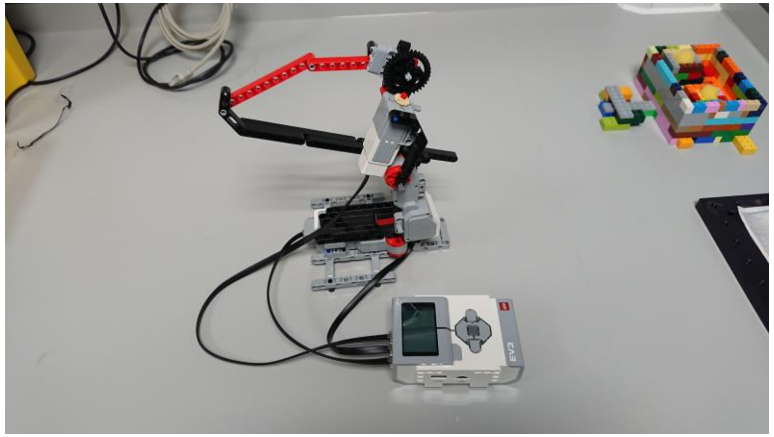
- The phantom hasn't change from the previous version but the old LEGO kit is not anymore available (we use the new kit LEGO 10698).
- The task consists in the *manual registration* of the robot and targeting of selected points
- The 'towers' of the phantom (see next slide are optional but can be built for *automatic registration* -> 'trenta e lode'…but remember: no grade :-).

Instruction to build the robot and the phantom

- In the folder Instructions:
  - RobotAssemblyInstructions.pdf
  - PhantomAssemblyInstructions.pdf
  - MiscAssemblyInstructions.pdf (important: identify the connections of the motors and the name of the angles that will later define the DOF of the robot!)


Phantom


Robot and Phantom


Robot

Software

- For the lego brick (called EV3 from now on):
  - Install ev3dev (using a memory card provided), following the instructions:

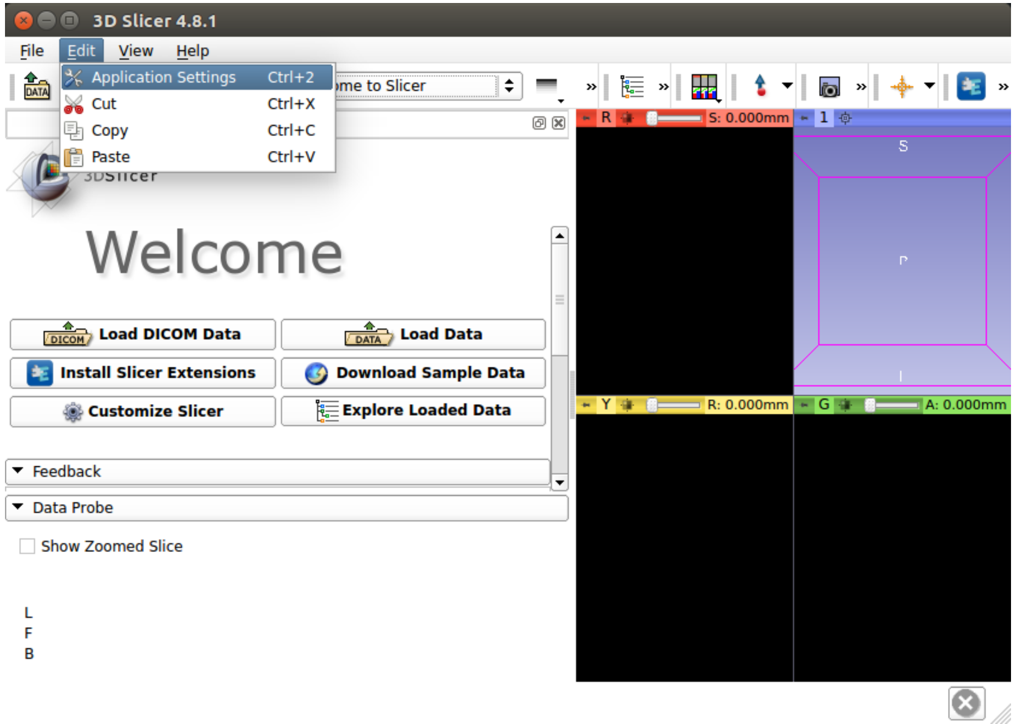
    http://www.ev3dev.org/docs/getting-started
  - The brick must be connected to the internet (use the USB port and the instructions):

  http://www.ev3dev.org/docs/tutorials/connecting-to-the-internet-via-usb/

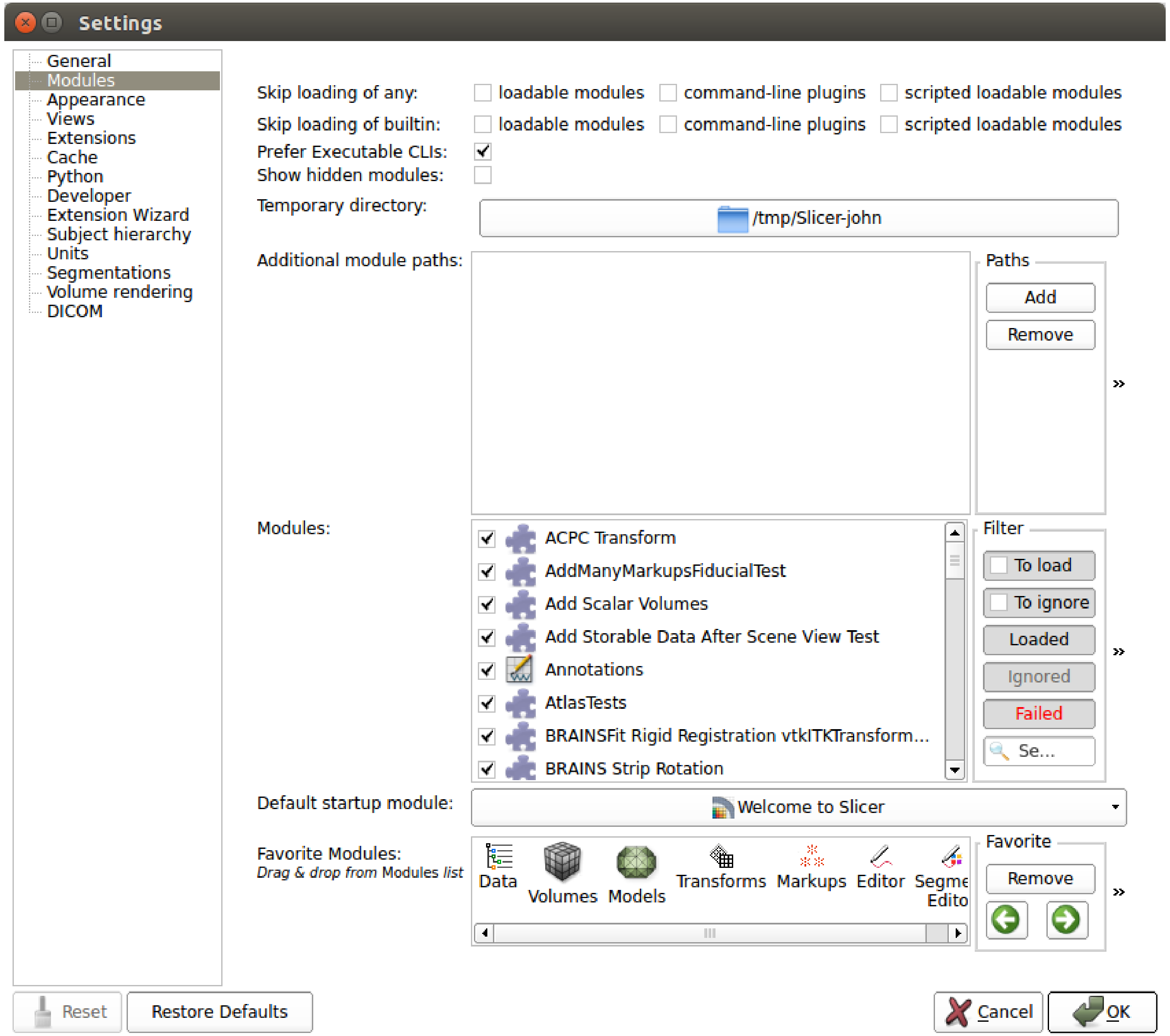
  - Copy and paste the files from the Python folder into EV3 device (hint: you may use SSH commands; in Windows install ‘Putty’).

Software (PC, Linux, …)

- Download Slicer: www.slicer.org (this workshop works on 4.8 version and similar versions)
- Open the 'Application Settings' by clicking 'Edit->Application Settings':



- Go to the ‘Modules’ tab:



Skip loading of any: □ loadable modules □ command-line plugins □ scripted loadable modules

Skip loading of builtin: □ loadable modules □ command-line plugins □ scripted loadable modules

Prefer Executable CLIs: ☑

Show hidden modules: □

Temporary directory: /tmp/Slicer-john

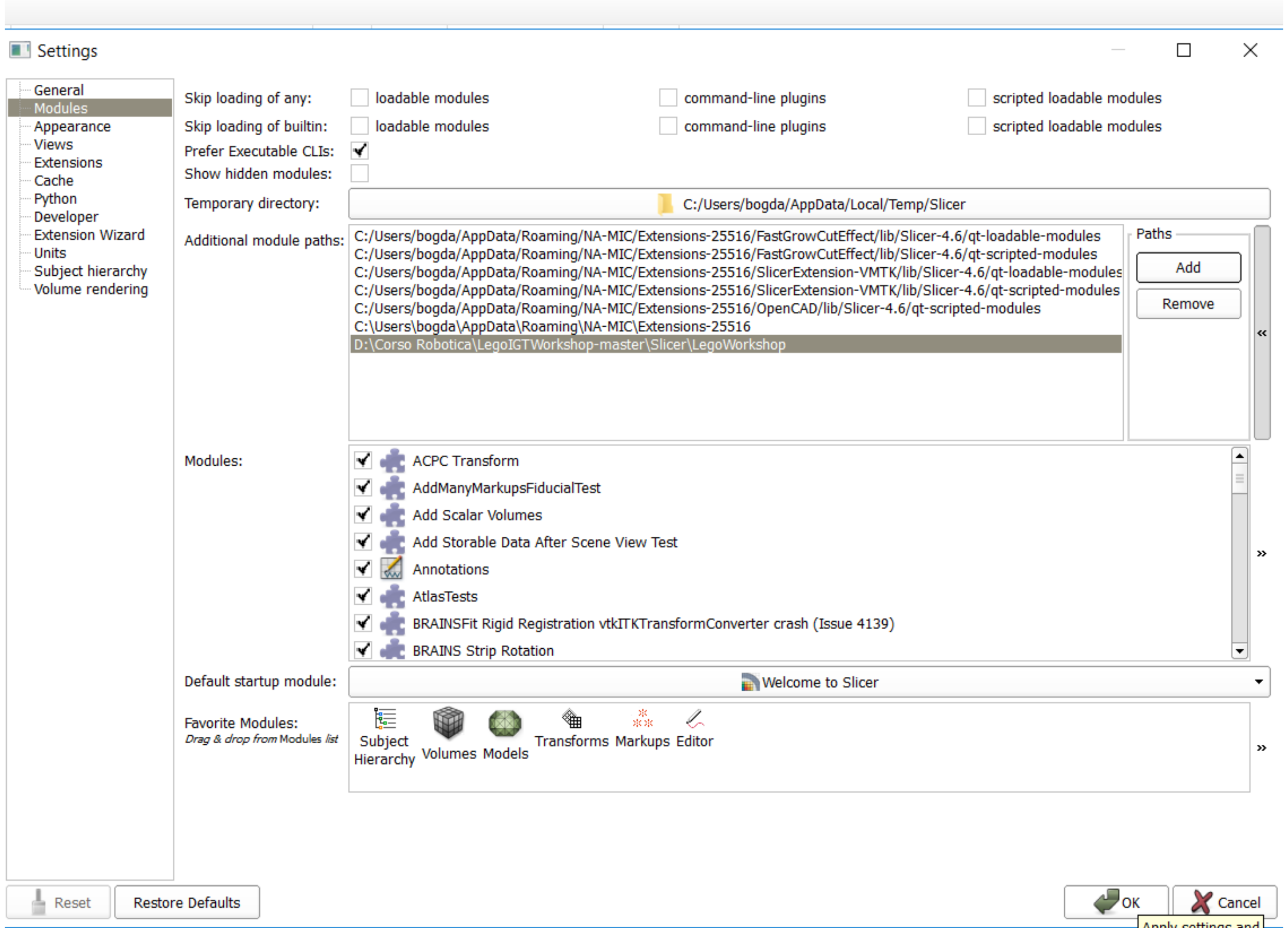
Additional module paths:

Modules:
☑ ACPC Transform
☑ AddManyMarkupsFiducialTest
☑ Add Scalar Volumes
☑ Add Storable Data After Scene View Test
☑ Annotations
☑ AtlasTests
☑ BRAINSFit Rigid Registration vtkITKTransform...
☑ BRAINS Strip Rotation

Default startup module: Welcome to Slicer

Favorite Modules:
Drag & drop from Modules list
Data, Volumes, Models, Transforms, Markups, Editor, Segme Edito

- Add a path under Additional Module Paths which points to the folder named LegoWorkshop (downloaded from the page of the Robotics course) in this repository:



Skip loading of any: □ loadable modules □ command-line plugins □ scripted loadable modules

Skip loading of builtin: □ loadable modules □ command-line plugins □ scripted loadable modules

Prefer Executable CLIs: ☑

Show hidden modules: □

Temporary directory: C:/Users/bogda/AppData/Local/Temp/Slicer

Additional module paths:

```
C:/Users/bogda/AppData/Roaming/NA-MIC/Extensions-25516/FastGrowCutEffect/lib/Slicer-4.6/qt-loadable-modules
C:/Users/bogda/AppData/Roaming/NA-MIC/Extensions-25516/FastGrowCutEffect/lib/Slicer-4.6/qt-scripted-modules
C:/Users/bogda/AppData/Roaming/NA-MIC/Extensions-25516/SlicerExtension-VMTK/lib/Slicer-4.6/qt-loadable-modules
C:/Users/bogda/AppData/Roaming/NA-MIC/Extensions-25516/SlicerExtension-VMTK/lib/Slicer-4.6/qt-scripted-modules
C:/Users/bogda/AppData/Roaming/NA-MIC/Extensions-25516/OpenCAD/lib/Slicer-4.6/qt-scripted-modules
C:\Users\bogda\AppData\Roaming\NA-MIC\Extensions-25516
D:\Corso Robotica\LegoIGTWorkshop-master\Slicer\LegoWorkshop
```

Modules:

☑ ACPC Transform
☑ AddManyMarkupsFiducialTest
☑ Add Scalar Volumes
☑ Add Storable Data After Scene View Test
☑ Annotations
☑ AtlasTests
☑ BRAINSFit Rigid Registration vtkITKTransformConverter crash (Issue 4139)
☑ BRAINS Strip Rotation

Default startup module: Welcome to Slicer

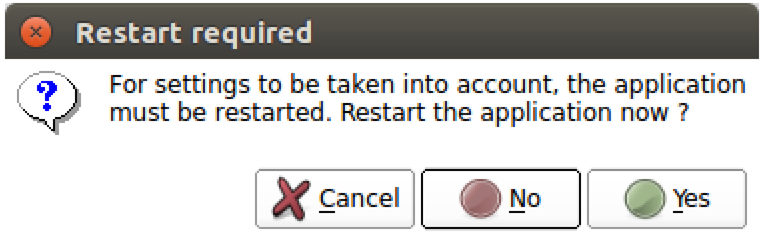
Favorite Modules: *Drag & drop from Modules list*

Subject Hierarchy, Volumes, Models, Transforms, Markups, Editor

Apply settings and

- The directory should be then in the list

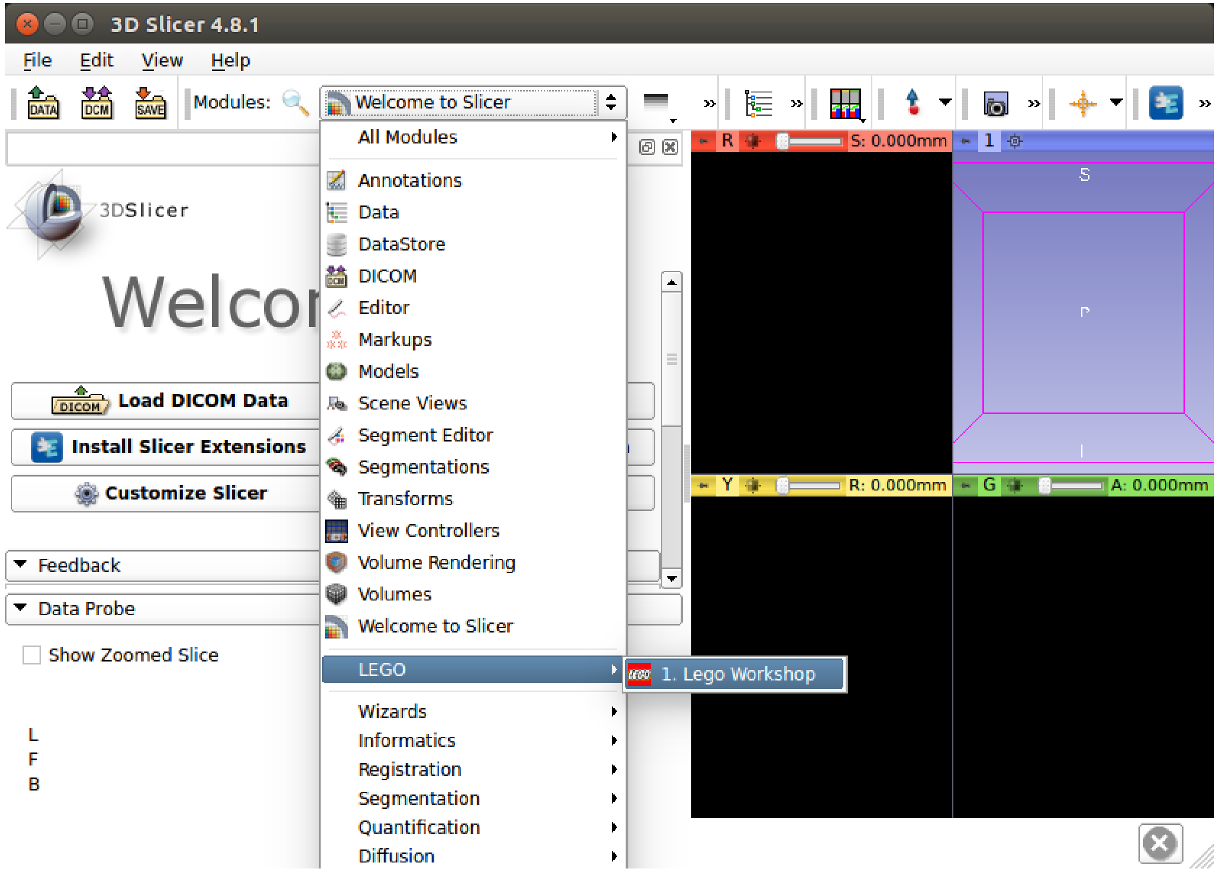
- This will require a reboot of the program to take effect:



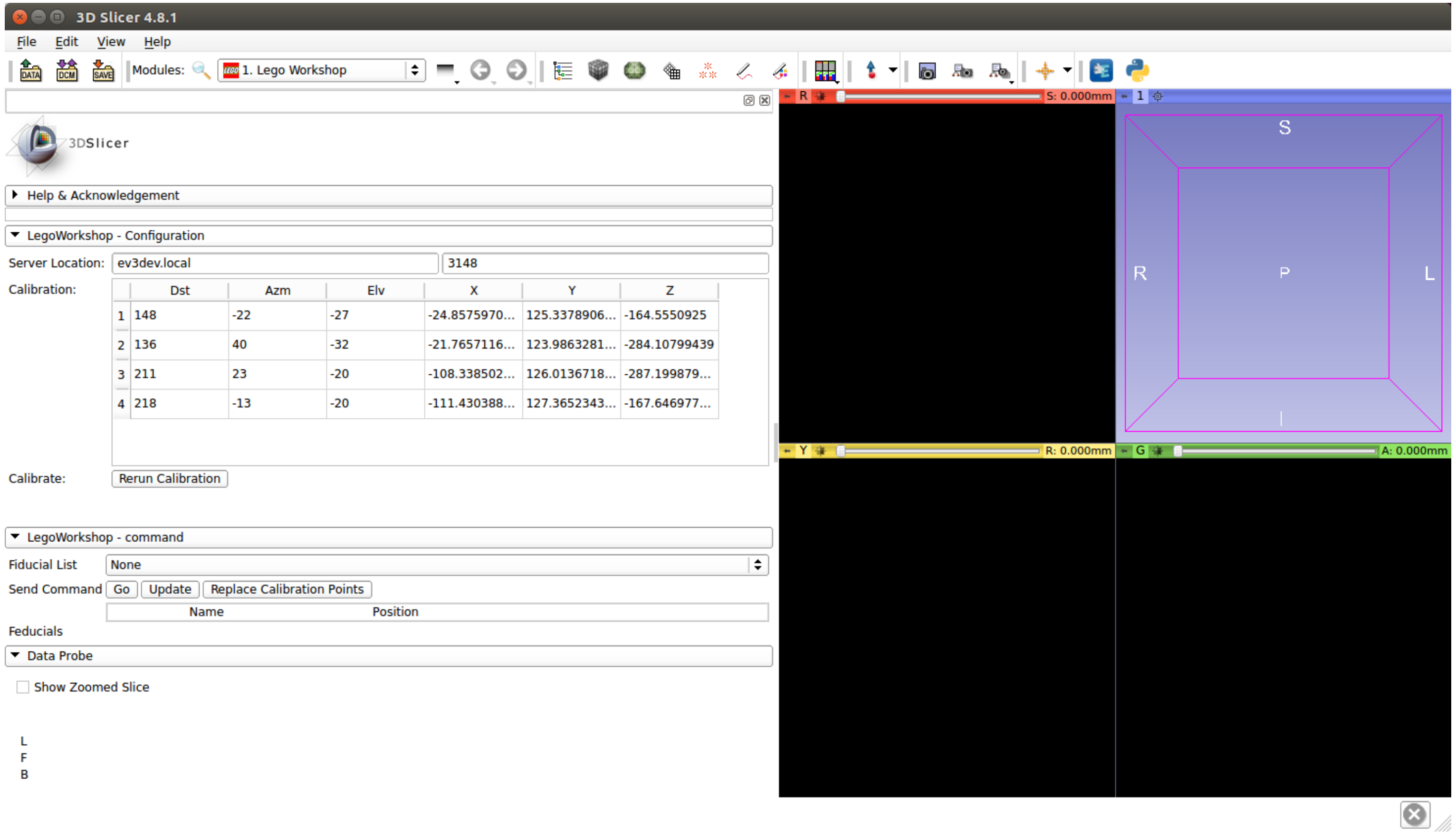
Restart required

For settings to be taken into account, the application must be restarted. Restart the application now ?

- To use the module, load it from the Modules menu:



- Make sure that under `LegoWorkshop - Configuration` the server address matches the address of your brick, (probably `ev3dev.local`).
- If `ev3dev.local` doesn't work, get the IP of the EV3 from the menu `WirelessAndNetowrks->AllNetowrkConnections->[Wired or other]->IPv4`.
- If the module loaded correctly it should look something like the following:



LegoWorkshop - Configuration

Server Location: ev3dev.local 3148

Calibration:

	Dst	Azm	Elv	X	Y	Z
1	148	-22	-27	-24.8575970...	125.3378906...	-164.5550925
2	136	40	-32	-21.7657116...	123.9863281...	-284.10799439
3	211	23	-20	-108.338502...	126.0136718...	-287.199879...
4	218	-13	-20	-111.430388...	127.3652343...	-167.646977...

Calibrate: Rerun Calibration

LegoWorkshop - command

Fiducial List: None

Send Command: Go | Update | Replace Calibration Points

Name	Position

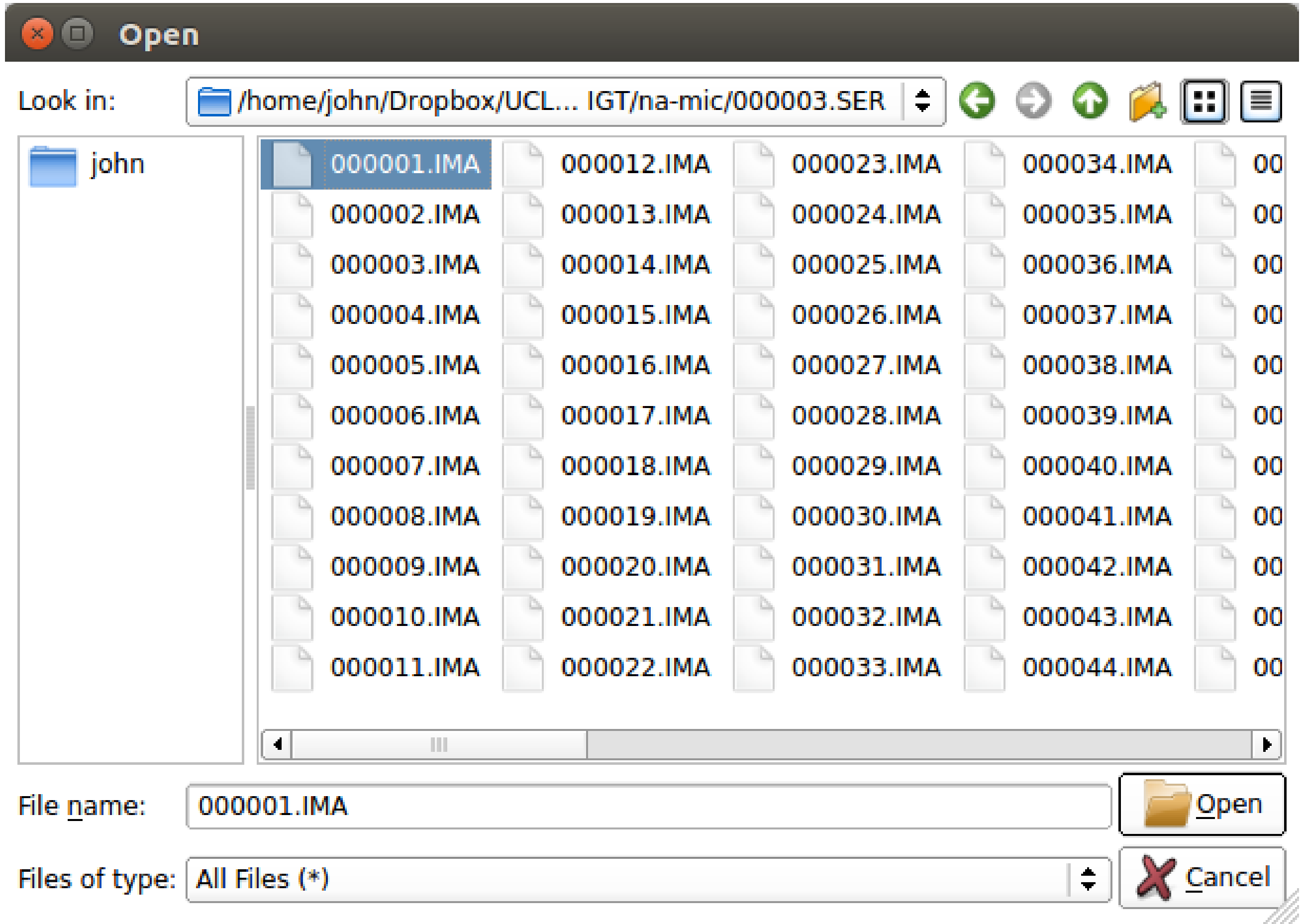
Feducials

Data Probe

□ Show Zoomed Slice

L
F
B

- Download the CT volume of the LEGO phantom (http://wiki.na-mic.org/Wiki/images/6/69/000003.SER.zip) and extract it somewhere. Now open that data with `File->Add Data` and point to the first file in the series:



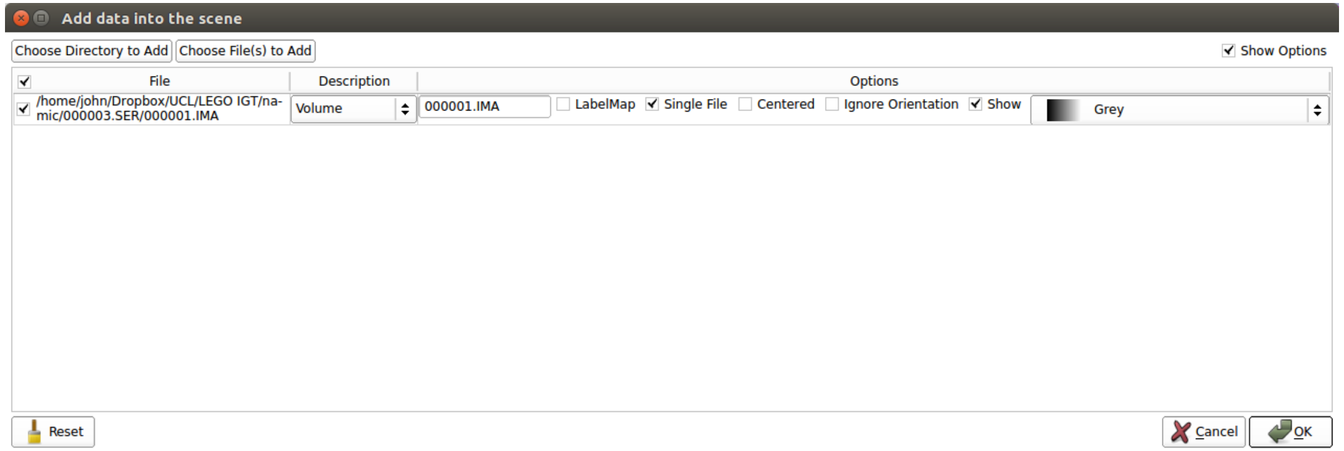
Look in: /home/john/Dropbox/UCL... IGT/na-mic/000003.SER

000001.IMA	000012.IMA	000023.IMA	000034.IMA	00
000002.IMA	000013.IMA	000024.IMA	000035.IMA	00
000003.IMA	000014.IMA	000025.IMA	000036.IMA	00
000004.IMA	000015.IMA	000026.IMA	000037.IMA	00
000005.IMA	000016.IMA	000027.IMA	000038.IMA	00
000006.IMA	000017.IMA	000028.IMA	000039.IMA	00
000007.IMA	000018.IMA	000029.IMA	000040.IMA	00
000008.IMA	000019.IMA	000030.IMA	000041.IMA	00
000009.IMA	000020.IMA	000031.IMA	000042.IMA	00
000010.IMA	000021.IMA	000032.IMA	000043.IMA	00
000011.IMA	000022.IMA	000033.IMA	000044.IMA	00

File name: 000001.IMA

Files of type: All Files (*)

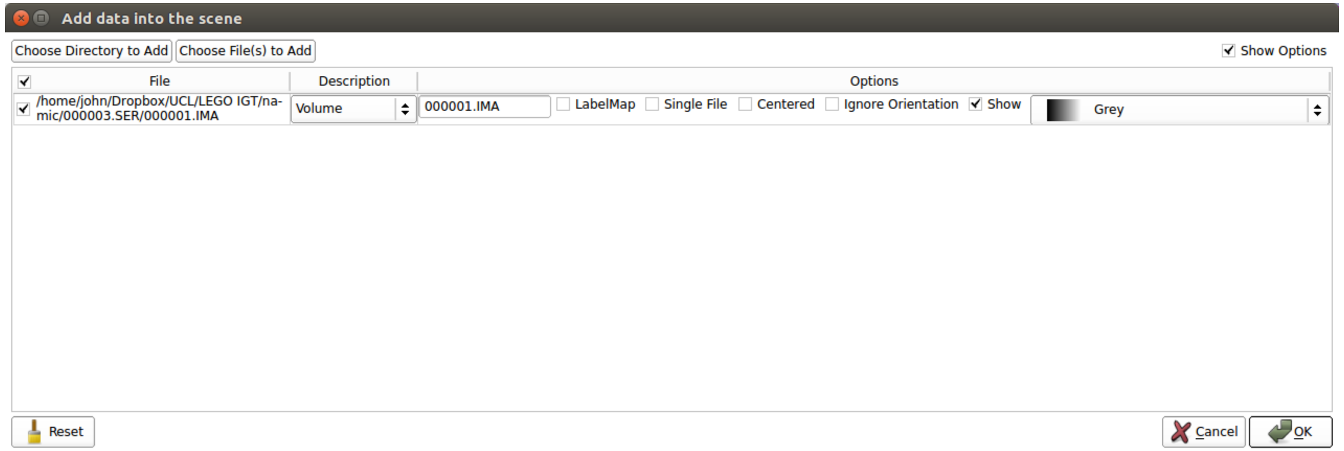
- Show additional options:


Add data into the scene

Choose Directory to Add | Choose File(s) to Add | ☑ Show Options

☑ File	Description	Options
☑ /home/john/Dropbox/UCL/LEGO IGT/na-mic/000003.SER/000001.IMA	Volume	000001.IMA □ LabelMap ☑ Single File □ Centered □ Ignore Orientation ☑ Show Grey

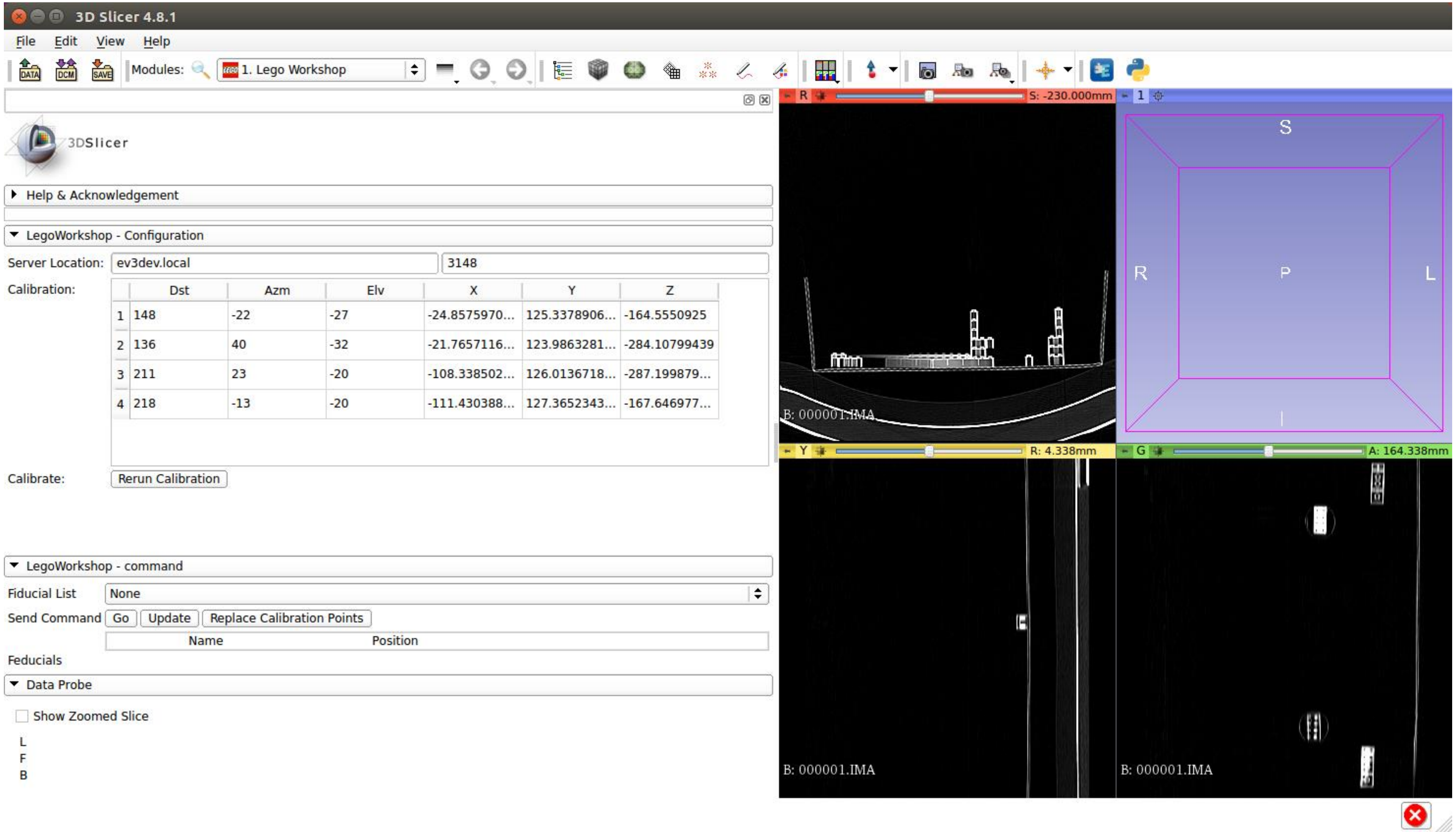
- Uncheck the ‘Single File’ box:


Add data into the scene

Choose Directory to Add | Choose File(s) to Add | ☑ Show Options

☑ File	Description	Options
☑ /home/john/Dropbox/UCL/LEGO IGT/na-mic/000003.SER/000001.IMA	Volume	000001.IMA □ LabelMap □ Single File □ Centered □ Ignore Orientation ☑ Show Grey

- Click ‘OK’. Now, you should see the CT scan of a LEGO phantom:



3D Slicer 4.8.1

LegoWorkshop - Configuration

Server Location: ev3dev.local 3148

Calibration:

	Dst	Azm	Elv	X	Y	Z
1	148	-22	-27	-24.8575970...	125.3378906...	-164.5550925
2	136	40	-32	-21.7657116...	123.9863281...	-284.10799439
3	211	23	-20	-108.338502...	126.0136718...	-287.199879...
4	218	-13	-20	-111.430388...	127.3652343...	-167.646977...

Calibrate: Rerun Calibration

LegoWorkshop - command

Fiducial List: None

Send Command: Go | Update | Replace Calibration Points

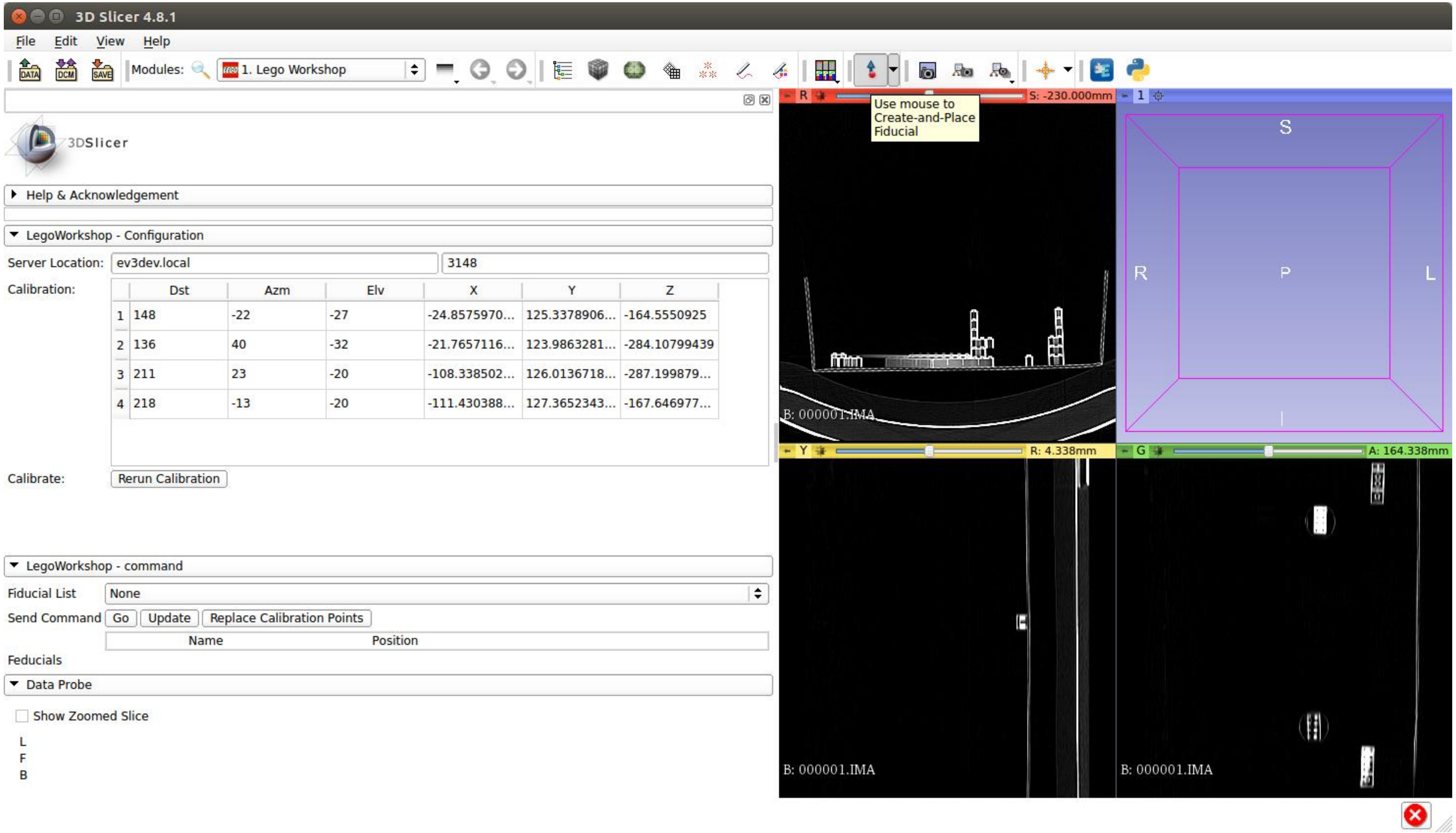
Name	Position

Feducials

Data Probe

□ Show Zoomed Slice

- Then add a Fiducial to the point you want to target by clicking on the icon with the red dot and blue arrow:



LegoWorkshop - Configuration

Server Location: ev3dev.local 3148

Calibration:

	Dst	Azm	Elv	X	Y	Z
1	148	-22	-27	-24.8575970...	125.3378906...	-164.5550925
2	136	40	-32	-21.7657116...	123.9863281...	-284.10799439
3	211	23	-20	-108.338502...	126.0136718...	-287.199879...
4	218	-13	-20	-111.430388...	127.3652343...	-167.646977...

Calibrate: Rerun Calibration

LegoWorkshop - command

Fiducial List: None

Send Command: Go | Update | Replace Calibration Points

Name	Position

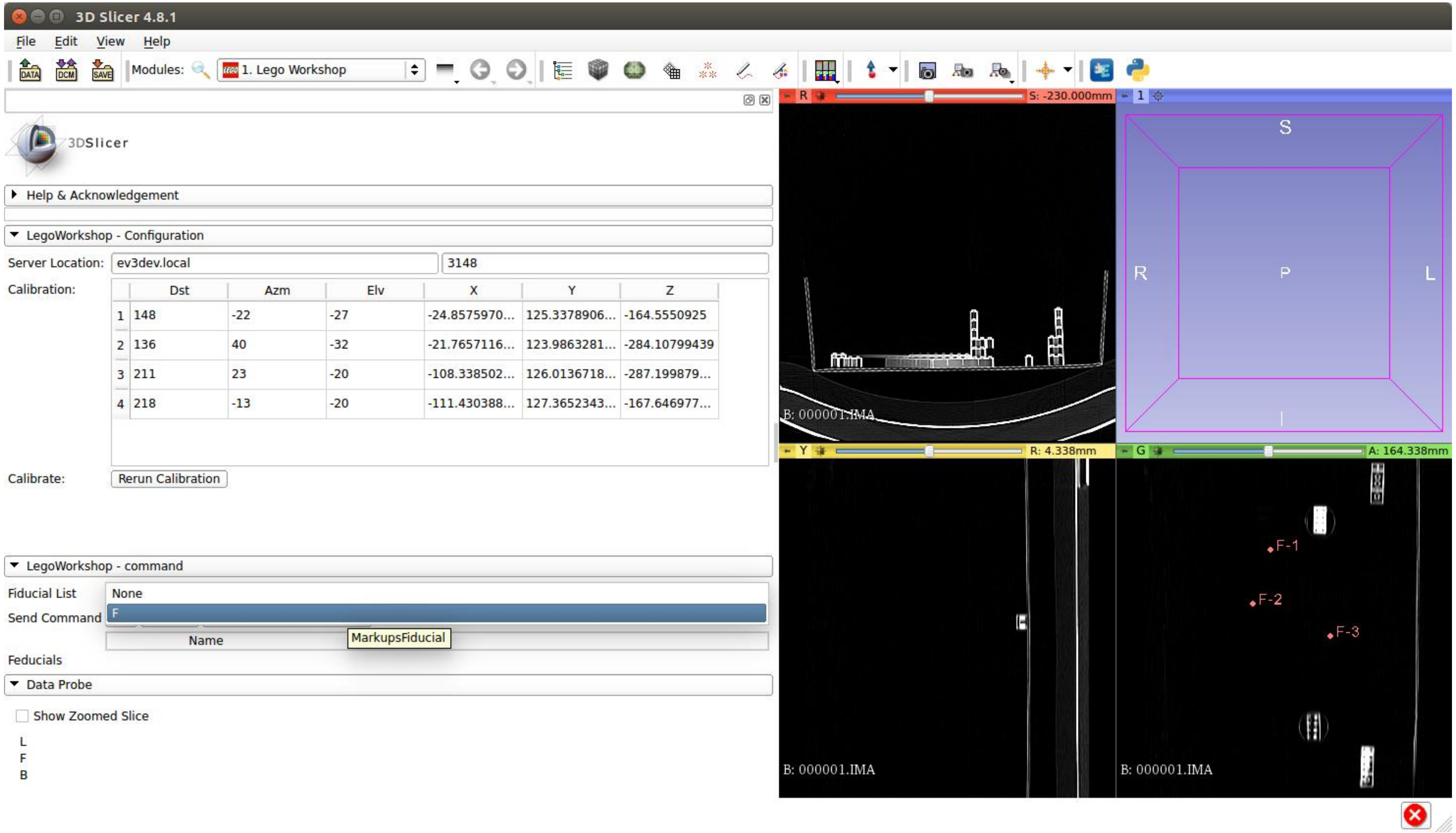
Feducials

Data Probe

□ Show Zoomed Slice

L
F
B

- Then click somewhere you want the robot to probe, and then choose the fiducial namespace (`F`) and that position will displayed on the list:



Server Location: ev3dev.local 3148

Calibration:

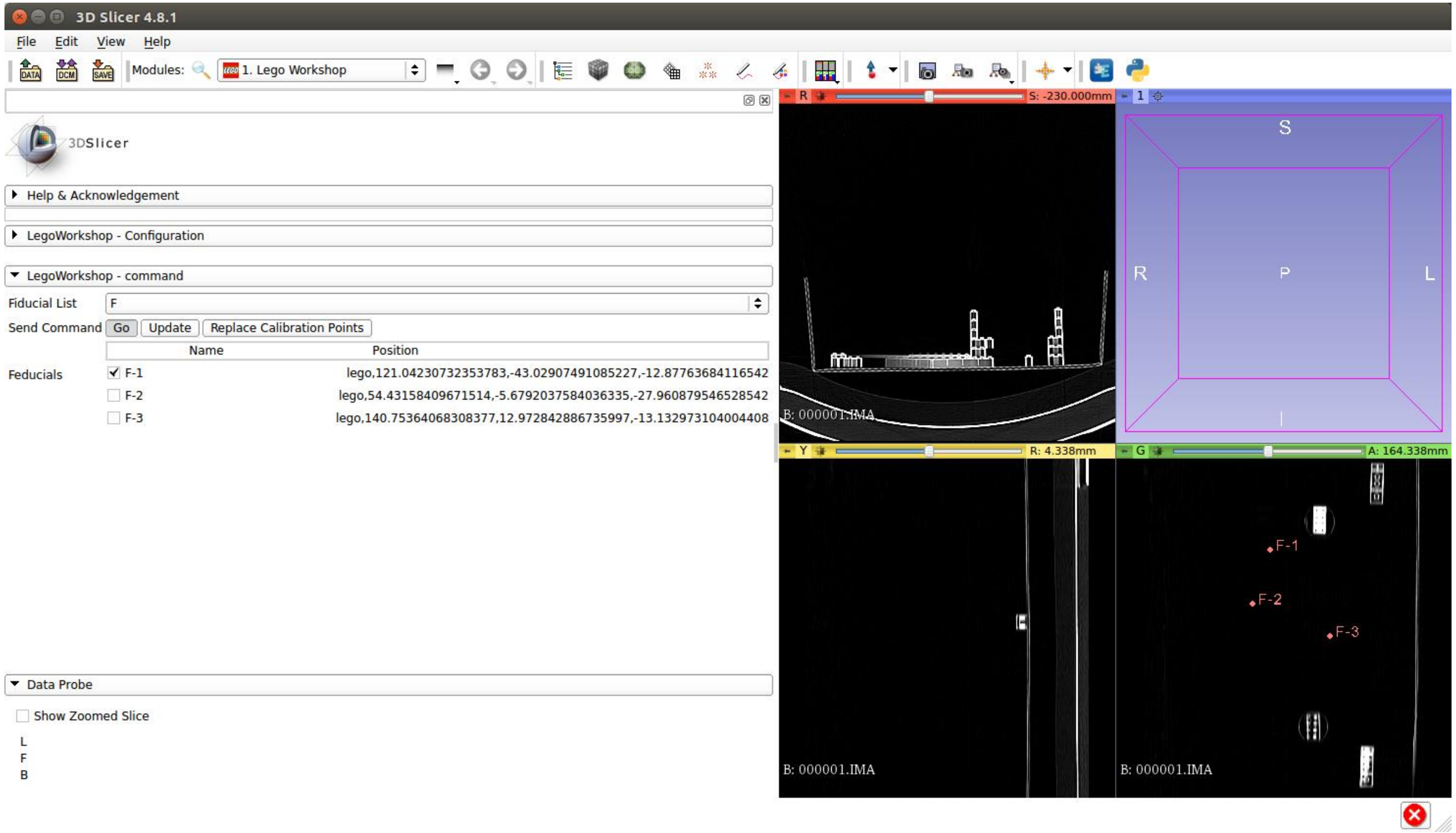
	Dst	Azm	Elv	X	Y	Z
1	148	-22	-27	-24.8575970...	125.3378906...	-164.5550925
2	136	40	-32	-21.7657116...	123.9863281...	-284.10799439
3	211	23	-20	-108.338502...	126.0136718...	-287.199879...
4	218	-13	-20	-111.430388...	127.3652343...	-167.646977...

Calibrate: Rerun Calibration

Fiducial List: None / F

Send Command

- Then choose which point(s) you want the robot to 'probe' by ticking the box next to them. When you are ready (and assuming you are running `lego-workshop.py`), press the `Go` button:



Fiducial List: F

Send Command: Go | Update | Replace Calibration Points

	Name	Position
Feducials	☑ F-1	lego,121.04230732353783,-43.02907491085227,-12.87763684116542
	□ F-2	lego,54.43158409671514,-5.6792037584036335,-27.960879546528542
	□ F-3	lego,140.75364068308377,12.972842886735997,-13.132973104004408

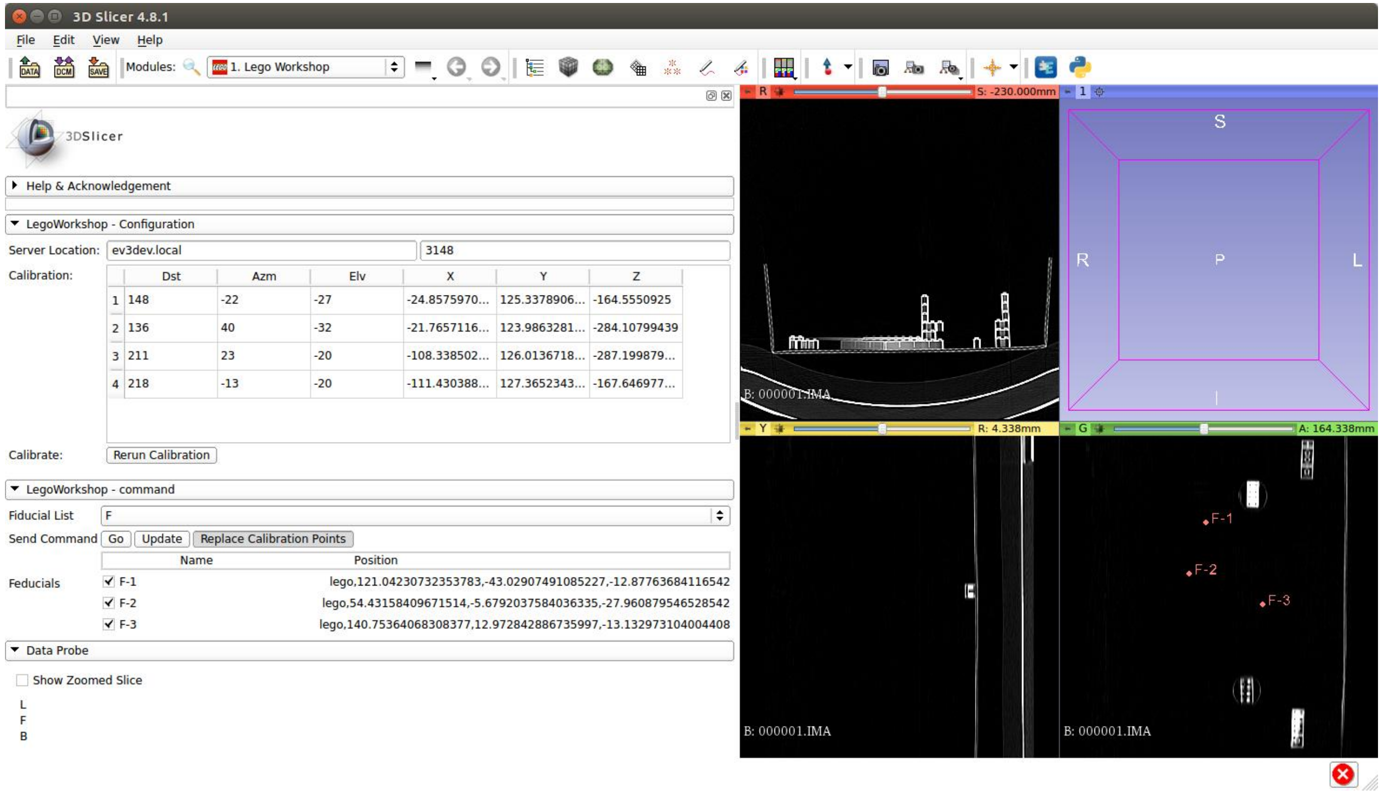
- This should make the robot move!

Manual registration of the robot (basic task)

- The previous calibration was already programmed into Slicer, but what happen if you have to move the robot somewhere else around the phantom?(while still having it within range of the injector)
- This is done by performing a manual registration through the selection of at least 3 fiducials and getting measurements of how those relate to the robot in the real world

Manual registration of the robot (basic task)

- Select a set of at least 3 fiducials and press the ‘Replace Calibration Points’ button (hint: use ‘Update’ after the selection of fiducials):



Server Location: ev3dev.local 3148

Calibration:

	Dst	Azm	Elv	X	Y	Z
1	148	-22	-27	-24.8575970...	125.3378906...	-164.5550925
2	136	40	-32	-21.7657116...	123.9863281...	-284.10799439
3	211	23	-20	-108.338502...	126.0136718...	-287.199879...
4	218	-13	-20	-111.430388...	127.3652343...	-167.646977...

Calibrate: Rerun Calibration

Fiducial List: F

Send Command: Go | Update | Replace Calibration Points

Feducials

Name	Position
☑ F-1	lego,121.04230732353783,-43.02907491085227,-12.87763684116542
☑ F-2	lego,54.43158409671514,-5.6792037584036335,-27.960879546528542
☑ F-3	lego,140.75364068308377,12.972842886735997,-13.132973104004408

□ Show Zoomed Slice

L
F
B

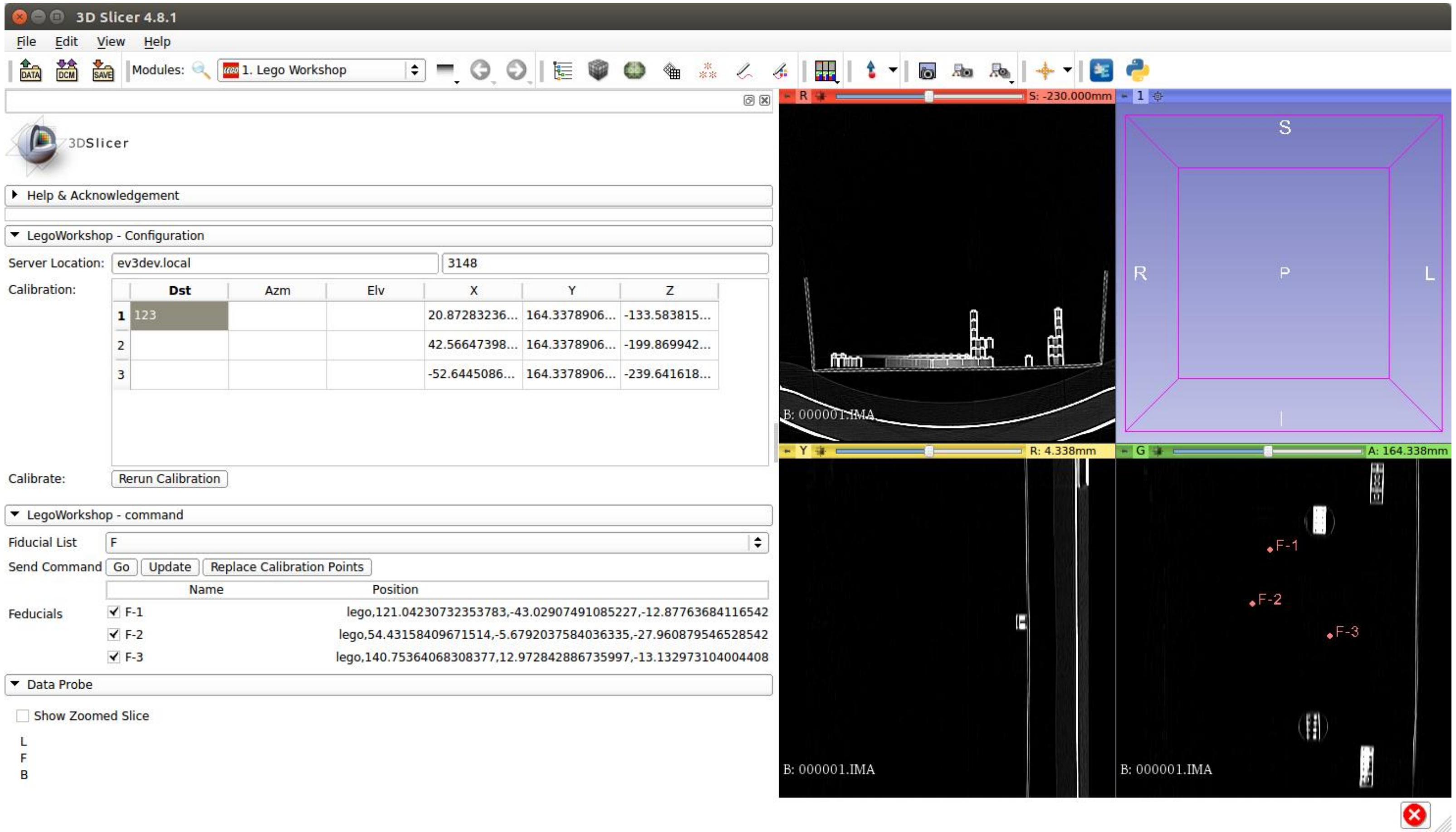
Manual registration of the robot (basic task)

- Note that the inject motor's encoder is spotty, and sometimes doesn't work so it is currently not implemented (`lego-debug.py` will either show 0 or a huge number), so you have to measure the distance from the orange circle of the upright large motor to your calibration point in millimeters, and that value will be `Dst`:

```
***************************
robot@ev3dev:~/lego-igt-workshop$ Python/lego-debug.py
Press the touch sensor to read the motor positions
WARNING! The inject motor does not seem to work, you will have to measure that manually
Dst Azm Elv
-1467 38 44
-1467 38 44
***************************
```

Manual registration of the robot (basic task)

- Enter those numbers into the table:



Server Location: ev3dev.local 3148

Calibration:

	Dst	Azm	Elv	X	Y	Z
1	123			20.87283236...	164.3378906...	-133.583815...
2				42.56647398...	164.3378906...	-199.869942...
3				-52.6445086...	164.3378906...	-239.641618...

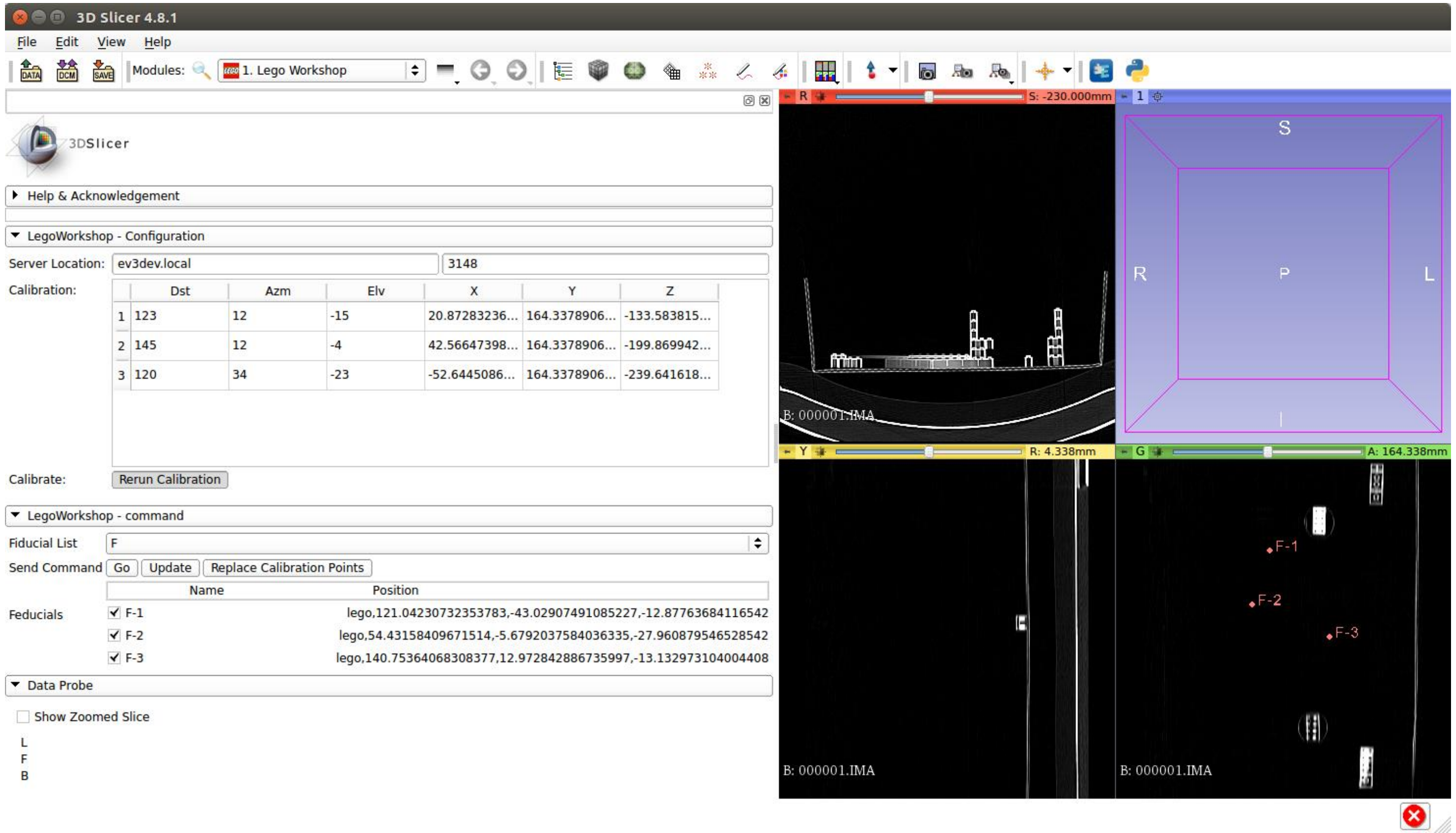
Fiducial List: F

Feducials

Name	Position
☑ F-1	lego,121.04230732353783,-43.02907491085227,-12.87763684116542
☑ F-2	lego,54.43158409671514,-5.6792037584036335,-27.960879546528542
☑ F-3	lego,140.75364068308377,12.972842886735997,-13.132973104004408

Manual registration of the robot (basic task)

- Then press the `Rerun Calibration` button to get a new calibration:



Server Location: ev3dev.local 3148

Calibration:

	Dst	Azm	Elv	X	Y	Z
1	123	12	-15	20.87283236...	164.3378906...	-133.583815...
2	145	12	-4	42.56647398...	164.3378906...	-199.869942...
3	120	34	-23	-52.6445086...	164.3378906...	-239.641618...

Calibrate: Rerun Calibration

Fiducial List F

Send Command Go Update Replace Calibration Points

Feducials

Name	Position
☑ F-1	lego,121.04230732353783,-43.02907491085227,-12.87763684116542
☑ F-2	lego,54.43158409671514,-5.6792037584036335,-27.960879546528542
☑ F-3	lego,140.75364068308377,12.972842886735997,-13.132973104004408

- Now, you can test out your new calibration

Manual registration of the robot (basic task)

- Note that if you think something is wrong you can set `Check_Calibration=True` in `LegoWorkshop.py` and if you run Slicer from a terminal you can get the details of the linear algebra, including the RMSE which (if you used more than 3 points) lets you know how well the calibration points agree on a registration (see also the previous lesson for details on how to register a set of points).

Automatic registration of the robot (advanced task)

- The robot can be equipped with an ultrasonic sensor, which can be used to sense the phantom and perform a fully automated registration (similar to how registration is done in the OR). However, this has not been implemented in the code, so it is up to you to take on this challenge. Good luck!
- Follow this tutorial:

https://na-mic.org/wiki/File:AnAccessibleHandsOnTutorialSystemForIGTAndMedicalRobotics.pdf

Assesment of targeting accuracy (the output of the project)

- Evaluate the target accuracy of the manual registration algorithm
- Evaluate the accuracy of the advanced registration algorithm
- The output of the project will be given by the results table and evenually a manual registration test in real-time

Buon lavoro!
Augurando.it