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Humanoid Robotics

Assignment 1

Due Thursday, April 17th, before class.

Perception Basics:

In the following tasks of this exercise sheet we consider two humanoid robots, **H1** and **H2**, working in a household environment. H1 is equipped with a time-of-flight camera **C1** with a resolution of **640x480** pixels. In comparison, H2 uses a **1920x1080** pixel stereo camera **C2** to perceive the world. Both cameras are mounted on the heads of the humanoids and are intrinsically and extrinsically calibrated. Use the accompanying Jupyter python notebook to answer all the questions.

1. **Homogenous Coordinates**
   a. Explain why Homogenous coordinates are beneficial compared to using separate Euclidean rotation and translation matrices.

      (1 point)

   b. Discuss the specific implications this has for simplifying the process of chaining multiple transformations and inverting them, which are common requirements in robotic perception and control.

      (1 point)

2. **Calibration**
   a. In order to extend its application range, we decided to use H1 outdoors as well. However, due to the higher complexity of this domain, it was decided to replace its current camera with C2 in order to benefit from its higher camera resolution. Therefore, the two cameras need to be swapped. What kind of calibration should be done? **Justify your answer.**

      (1 point)

   b. As H1 was walking outside, he accidentally hit his head on a high hanging pole and the camera got dislodged. Fortunately, C2 suffered no external damage and was put back in place. What kind of calibration should be done in this case? **Justify your answer.**

      (1 point)

3. **Pinhole Projection**
   a. Write a function to derive the intrinsic matrix given the camera constant, principal point and pixel scaling factors. **Print the resulting matrix.**

      (1 point)

   b. Implement a function that takes as input 3D points in Euclidean coordinates, converts them to Homogenous coordinates and outputs their corresponding 2D image coordinates. **Visualize the 2D image coordinates on a scatter plot.**

      (2 points)

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4. Intrinsic Parameter Estimation Using World-to-Camera Transformations

Suppose H1 is positioned so that its torso is positioned at **(2, 3, 1)** in the world coordinate system, with the torso's axes aligned with the world axes. Unfortunately, C2 has to be replaced by another camera that can provide better depth estimates. We assume that the transformation between the torso frame and the camera frame is known due to the fixed location of the 3D printed camera mount. In particular, the camera is mounted 1 meter above the torso. In the torso frame, the camera's position is **(0, 0, 1)**, and its coordinate system is rotated relative to the torso frame so that the camera's x-axis remains aligned with the torso's x-axis, the camera's y-axis points downward (opposite the torso's z-axis), and the camera's z-axis (pointing forward) is parallel to the torso's y-axis (i.e., horizontal with respect to the ground).

a. Plot a visualization of the three coordinate systems (world, torso, camera) at their current locations. (1 point)
b. Write a function to transform 3D points provided in the world coordinate system into the camera frame using homogeneous coordinates. The points are provided in the additional.csv files. (2 points)

Assume that the 3D points in the world frame are projected onto the image plane via a pinhole camera model using the intrinsic matrix given in the slides. The corresponding projected points have been estimated using a calibration procedure. Assume that there is **no scale difference** in x and y. Estimate the intrinsic parameters under the following conditions:

c. The 2D projections are noiseless. (2 points)
d. The 2D projections contain noise, and the number of correspondences exceeds the number of unknown parameters. (3 points)