Fiducial Detector: 2.0

JPL

December 7, 2012

1 Introduction

The fiducial detector provided solves for the 3-DOF position of a fiducial marker (provided in the attached `pdf` file), with an optional 6-DOF solver. As shown in Figure 1, the fiducial marker has an inner circle and an outer circle, segmented into black and white quadrants. The reference frame of the fiducial is also shown in Figure 1.

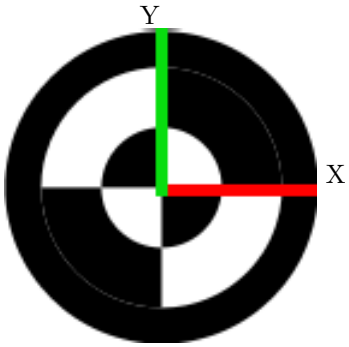


Figure 1: Fiducial marker with reference frame.

The provided detector currently only works with a stereo camera and takes as input an expected location of the marker as well as the left and right rectified images. Camera models must also be provided during setup and they must be **linearized camera models**. The camera models consist of:

- `focal_length_x` (in pixels)
- `focal_length_y` (in pixels)
- `image_center_x` (in pixels; nominally half the image width)
- `image_center_y` (in pixels; nominally half the image height)
- `G` $\in \mathbb{R}^{4\times4}$ (a homogeneous transform between the camera and the sensor reference frame [1])

From the provided "seeded location" of the marker, the algorithm works by searching locally for the marker in the image and returns when it converges to a matching pattern in image space. If the seeded location of the marker is significantly off, then the fiducial detector will fail to find a match and simply return the initial seeded location as the fiducial pose.

[1] The sensor reference frame is assumed to be the center of the left camera in the stereo pair. Thus for the left stereo camera model, it will likely be the case that `G` is identity, depending on the rectification process used.

2 Setup

Locate the file `fiducial.pdf` and print it. The produced marker should measure 0.00635m for the inner radius and 0.01270m for the outer radius. Print and cut a fiducial for each location on the arm(s) of which you intend to use it. While the number of fiducials and their locations have not been finalized, we recommend the locations as shown in Figure 2 and are open to discussion on what other teams think.

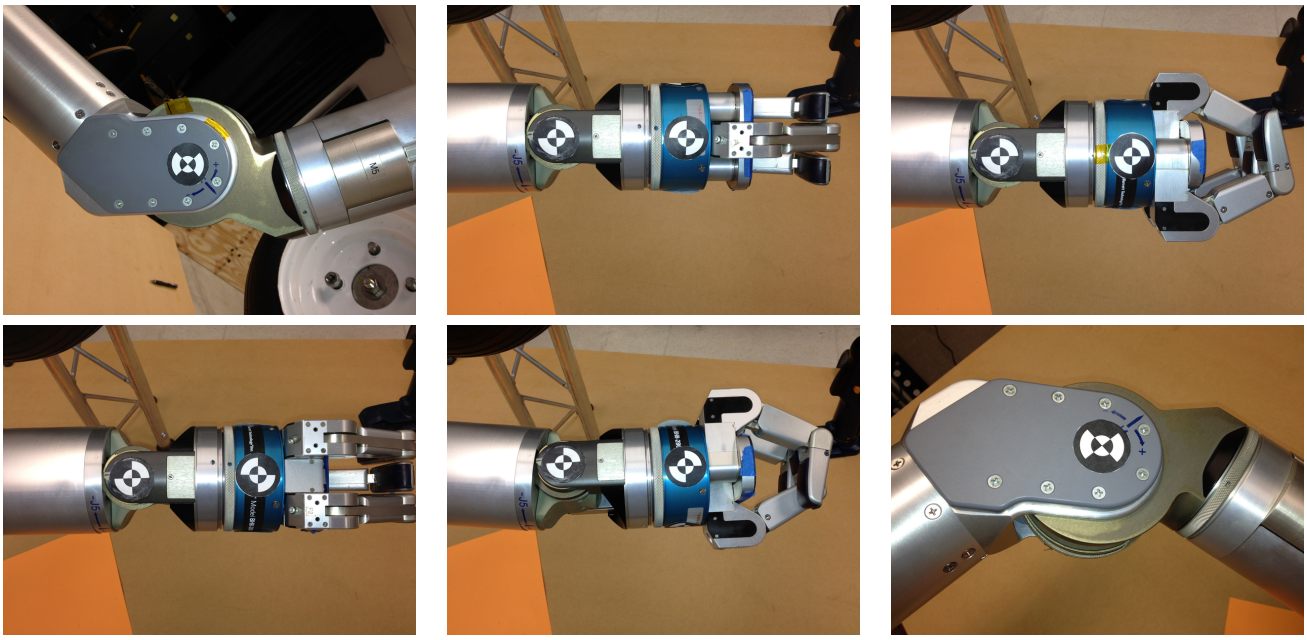


Figure 2: The fiducials shown are on the left arm only, and are symmetric for the right arm (not shown). In summary, there exists two markers on the elbow joint 4, one marker on the wrist at joint 6, and four markers around the hand at joint 7.

3 Release Notes

- The release of version 2.0 of this library has three main flavors of the fiducial detector. The first, which matches the fiducial at the pixel level. The second is similar to the first but includes a subpixel step, providing a more accurate depth calculation of the fiducial. Both only return an updated position of the fiducial. The third method uses pixel matching (first method) initially to obtain a coarse location and then gradient descent is used to refine the match provided a full 6DOF pose correction (position and orientation).
- The framework of this detector now consists of a convenience wrapper `fiducial_stereo.c` that instantiates two detectors for each camera (left and right). The main process function is now called `fiducial_stereo_process` and is where changes may be made to toggle the detector used (pixel or subpixel). A flag to the function, `full_pose`, may be passed to return the full 6DOF correction.
- Nominal testing using the example below on a Quad-core Intel Xeon 2.40GHz processor does fiducial matching of one fiducial:

  - at the pixel level in $\sim$ 5ms (200Hz).
  - at the subpixel level in $\sim$ 5.8ms (170Hz).
  - using gradient descent in $\sim$ 6.2ms (160Hz). This may drop significantly with increased iterations (occurs if the initial seed is far off).

- The parameters to be changed are `search_size`, `min_viewing_angle`, `dist_thresh`. `search_size` defines the template half-window search size in pixels (i.e. a `search_size` of 40 would be an 80×80 window). The larger this number, the longer the fiducial detector will take to converge. `min_viewing_angle` is the minimum angle (in degrees) for which to ignore markers that are pitched below this angle of incidence. `dist_thresh` is the allowable maximum distance (magnitude) between the initial and estimated fiducial location to be considered valid.

- Currently, `OpenCV` is needed to compile the test program, which is mainly only used to load and save the test images.

- The fiducial detector provided does not do any form of tracking or data association of markers. That is, if two fiducial markers are placed relatively close to one another, it is possible for the detector to converge to either marker. Thus it is important to space out the fiducials to avoid this mis-assocation (see Section 2 for our recommended fiducial locations)

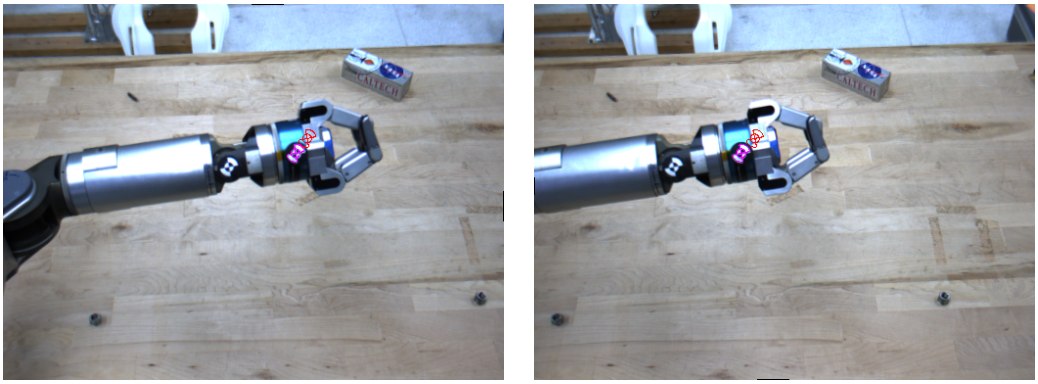
- Scores in the left image and right image fiducial match are output as part of the `fiducial_stereo_process` function. These can be used to threshold against good/bad matches.

4 Example

Starting with version 2.0, the source code will be provided and will be maintained by JPL. Source code for a test program has been provided to illustrate how to use the detector: `test.c`. The associated Makefile will compile the test program against the provided library and run the detector algorithm against two rectified test images (also provided) along with the camera models used to rectify those images. The initial seed location of the fiducial is defined in a text file: `initial_location.txt`. The user may further deviate the intial pose of the fiducial to ascertain the convergence of the gradient descent.

The output of the test program will be two debug images, one for the left camera and one for the right camera. Figure 3 shows both debug images with the seeded marker location in red and the converged location in magenta. Note that in the images, there are two fiducial markers spaced some distance apart to avoid the mis-association problem mentioned earlier.

The user is encouraged to familiarize him/herself with the test program and the initial location text file to see how the detector works and where it fails, before integrating into their main source tree. Any questions, comments, or concerns can be directed to `paul.hebert@jpl.nasa.gov`.



(a) (b)

Figure 3: (a) The left debug image. (b) The right debug image. In both images, the seeded location of the fiducial from kinematics is shown in red, and the converged estimated location from the detector is shown in magenta.