Todo:

New solidworks-> john?

Make kinematic equations

How to test on printer?

Automatic Calibration of a Delta Style 3D Printer

Problem:

A 3D printer must be able to accurately and reliably position itself in 3d space for correct operation. Due to the non-linear nature of the kinematic equations that drive the motion for a delta style 3D printer small mechanical misalignments can translate to large errors in the 3d motion. Manually fixing the mechanical misalignments can be a very time consuming and essentially impossible task for the user. Thus to achieve maximum effectiveness of the printer a software based calibration suite is needed.

Background information:

As 3d printers have continued to increase in popularity different style of printers have begun to emerge on the market. The style that will be discussed in this report is the “delta style”. The delta platform is a parallel robot platform that was originally developed for the high speed pick-and-place industry (SOURCE). Since (PEOPLE) first released their delta printer in (TIME) the popularity has continued to grow. The form factor offers many benefits for 3D printing, ranging from high acceleration to simple, robust construction.

The following diagram illustrates numerous parts of the printer that will be required to understand the report:

Endstops

Bed

End effector

Towers (alpha beta gamma)

Arms

Bed probe

Motors Belts carriages

The kinematic equations that translate the motor rotation into end effector positioning rely heavily on the mechanical structure of the printer. This section will explore the numerous sources where error can be introduced into the system. The first assumption that can be made is that the bed of the printer is perfectly flat. This is a reasonable assumption because the bed is a 3mm thick borosilicate glass plate. The common tolerance for this material is (THING) (SOURCE) which is so accurate as to be insignificant.

The second source of error is the towers of the printer. To begin, the towers are assumed to be straight. The carriages run on 12mm Hywin recirculating ball carriages, that have a tolerance of (XXX), which is insignificant. There are three main ways in which they can affect accuracy. Firstly, if the printer is viewed from above they should be at the vertices of and equilateral triangle, with the centroid of the triangle being collinear with the center of the bed. Secondly, they should be perfectly vertical, or in other words parallel to each other and perpendicular to the bed. Thirdly they should be facing towards the center of the bed and not rotated along a vertical axis. The following three diagrams graphically show these errors. In an attempt to reduce the number of variables that require tuning the third source of error will be eliminated. Based on the following equations (MAYBE?) this does not significantly affect the positional accuracy of the printer, it merely introduces rotation and backlash into the end effector.

A third source of error is the arms that connect the end effector to the carriages. To achieve maximum accuracy the arms should be measured and then grouped in pairs that are closest matched in length. The arms were measured using precision ball bearings, a granite surface plate and a mitutoyo vertical height gauge. The respective tolerances are (). Since the arms can be accurately measured and will not change, they do not need to be calibrated, they just simply need to be accounted for in the kinematic equations. To simplify the process the arm lengths will be entered in the kinematic equation as the average of the matched pairs (MAyBE). If each arm length is accounted for in the kinematics the system will become over constrained. In the real world model there is a certain amount of lash that the mathematical model cannot account for.

Building the kinematic equations:

We now have enough knowledge to begin assembling the kinematic equations that will drive the printer. Based on the assumptions discussed in the previous sections the model of the printer will be simplified, and then the equations derived.

Excel or matpy to make kinematics

Kinematics:

Have xyz position of each carriage (know distance down the tower and tower start plus tower end., just average) Assume tower is straight.

Intersection of the three arm lengths (intersection of three spheres, with various radii)

First do two arms intersection. This gives end effector position in a circle. Then do the third, this gives two possible points of intersection. Choose lowest

The calibration routine consists of two parts. The first is an algorithm that tunes the kinematic equations of the printer. This is the section that provides the greatest increase in overall accuracy, it makes the software model better match the physical system. The second will simply be a topographical mapping of the print surface. This section provides no correction in the x or y dimensions, it simply assures that the printer will remain a consistent height above the bed. Variations in height above the bed can be caused by adding an inaccurate substrate on top of the glass to help adhesion or due to small errors that remain in the model. It is critical to have a consistent height above the bed to assure the first layer of the print will stick to the bed.

Randomly vary some of the parameters

Calculate the deviation from the target position

Iterate

Decide to keep the new parameters or discard them

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Optimal parameters have been uncovered

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| **Algorithm\Criteria** | **Computation power required** | **High Dimension Capable** | **Mix of Exploration & Exploitation** |
| Gradient Descent | Low | Yes | No |
| Simulated Annealing | Medium | Yes | Yes |
| Evolutionary Algorithms | High | Yes | Yes |