Manipulator calibration

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In this document, I explain in detail how to transform the coordinate system of manipulators into a reference system, that of the XY stage and microscope.

Definitions

- **y** is the XYZ coordinate vector of the manipulator, where each dimension refers to one of the motors. Coordinates are positive; 0 means the motor is at its minimum. This is the position provided by the manipulator through the serial port.
- **x** is the XYZ coordinate vector of the XY stage and microscope, when the pipette tip is placed in focus at the center of the field. This is what we call the coordinates of the pipette tip in the reference system.

The two vectors are related by an affine transformation:

$$\boldsymbol{x} = M\boldsymbol{y} + \boldsymbol{x_0}$$

where M is a matrix and $\mathbf{x}_0$ is the position of the pipette tip in the reference system when the motors are at the minimum position in all dimensions.

Primary calibration

We first move the microscope at the reference position $\mathbf{x}_r$; typically centered and a few millimeters above the preparation. Then the pipette tip is centered. We record $\mathbf{y}_r$=**y**. Thus we obtain:

$$\boldsymbol{x_r} = M\boldsymbol{y_r} + \boldsymbol{x_0}$$

Then we move the manipulator along the X axis by an amount δ. If we note $\mathbf{M}_X$ the first column vector of M, then the required change in microscope vector to center the pipette tip is:

$$\Delta\boldsymbol{x} = \boldsymbol{M}_X\delta$$

That is:

$$\boldsymbol{M}_X = \frac{1}{\delta}\Delta\boldsymbol{x}$$

We repeat the operation along the Y and Z axes, and thus we obtain the three column vectors of M. Finally we calculate $\mathbf{x}_0$:

$$\boldsymbol{x}_0 = \boldsymbol{x}_r - M\boldsymbol{y_r}$$

Precision check

In principle, a movement of 1 µm along an axis of the manipulator should correspond to a movement of 1 µm in the reference system. This means:

$$\|\boldsymbol{M}_X\| = \|\boldsymbol{M}_Y\| = \|\boldsymbol{M}_Z\| = 1$$

This can be checked.

Secondary calibration

When the pipette is changed, we simply recalculate $\mathbf{x}_0$ after having moved the pipette tip to the reference position:

$$\boldsymbol{x}_0 = \boldsymbol{x}_r - M\boldsymbol{y}_r$$

In principle, only pipette length should change. This means that:

$$\boldsymbol{x}_0^{new} = \boldsymbol{x}_0^{old} + \boldsymbol{M}_X\delta$$

for some value of δ.