Analyzing Kinematic Structure of Haptic Input Device

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Background

- Haptic devices make human-robot interaction intuitive by letting users physically feel contact forces and scaling up the workspace
- Focused on the Geomagic Touch (Fig. 1) a 6-DOF stylus-based device
- Developed a digital twin (Fig. 2) for virtual environments that reconstructs pose from joint-angle data
- End goal is to have verified virtual representation for controlling medical robots

Modelling

- Used Denavit-Hartenberg (DH) parameters (Fig. 4, 5) to model the geometry of each link
- Each row of DH parameter table has link length (d, a) and rotation (θ, α)
- Converted parameters to homogeneous transformation matrices to develop relative link orientations, ultimately stylus position
- Obtained live joint angle data from the device through OpenHaptics API Toolkit and custom C++, Python code

Verification

- Original parameters obtained from CAD model and measurement
- Optical table with precision-milled holes to test model position against real position (Fig. 3)
- Data collected on stylus position and grid-based position of current hole
- Three experiments, three trials each: Original Parameters, Error Matrix, Optimized Parameters
- Two calculated measurements:
  - Mean offset from idealized grid
  - Mean spacing among data points

Fig 1. The 3D Systems Geomagic Touch.

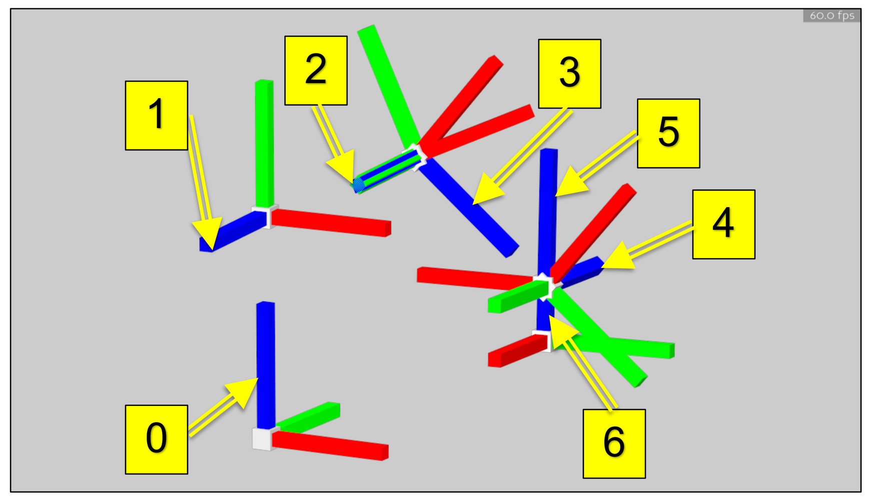

Fig 2. The digital kinematic model of a Geomagic Touch. Axes of a coordinate frame is represented by color: red for X, green for Y, blue for Z. The arrows point to the Z-axis of each frame, numbered as such:
0: Ground position (origin)
1: Swivel joint
2: First arm joint
3: Second arm joint
4. Gimbal roll
5. Gimbal pitch
6. Stylus roll

Fig 3. A Geomagic Touch at the optical table during the verification process.

Results

- Mean spacing steady among all trials, difference of only 0.56mm between max and min mean spacing (Fig. 6)
- Original parameters (Fig. 7) displayed greatest deviance, with the highest range of mean offset (8.22-9.93mm)
- Error matrix (Fig. 8) displayed least deviance, with the lowest range of mean offset (3.10 – 4.08mm) and very small variance (0.01mm) among spacing
- Optimized parameters (Fig. 9) halfway between error matrix and original in mean offset (6.09-6.34mm)
- Visible qualitative trends in data
  - Higher offset with origin distance
  - Matrix correction has upwards bend, signals nonlinear error
  - Clustering across different trials, little variance between circles

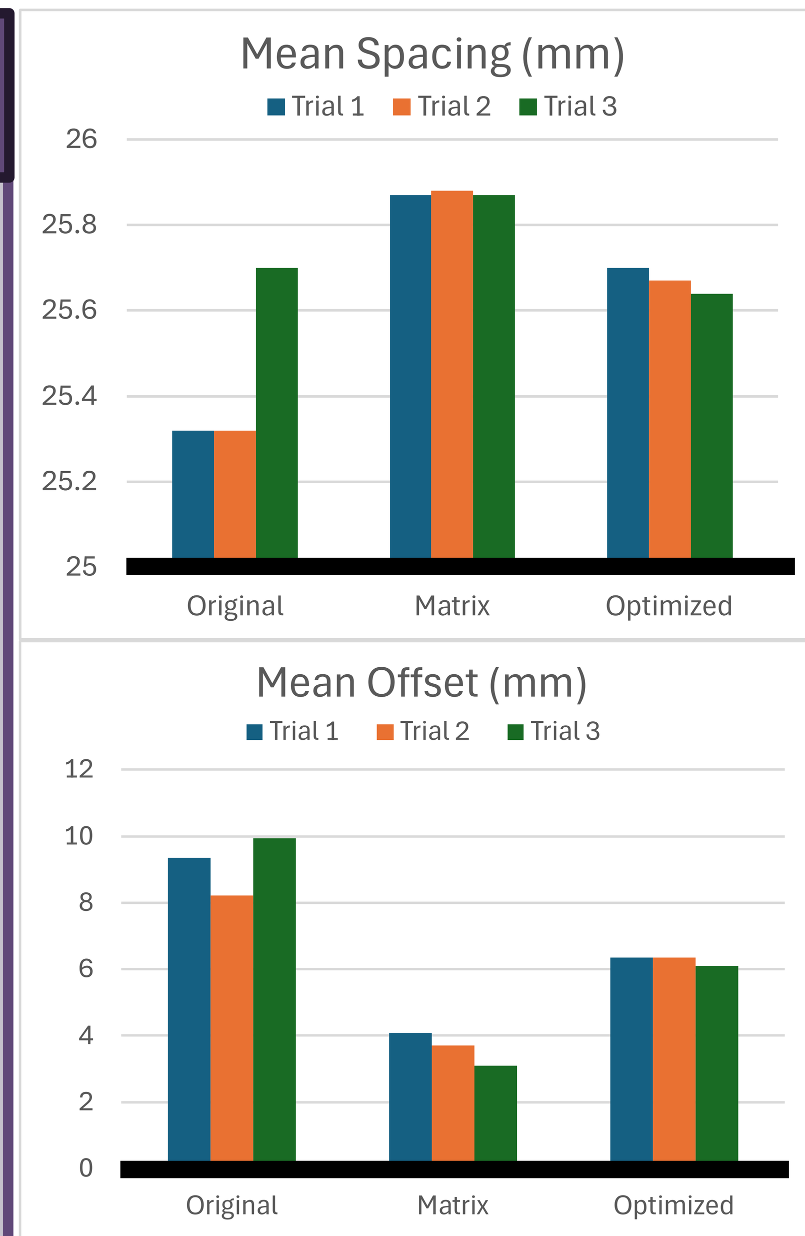

Fig 6. Mean error metrics for all experiments and trials. Black horizontal bar represents ideal values.

Conclusions

- Error matrix reduces offset error the most, but may be restricted to similar positions used in calculation
- Optimized parameters may be better in new positions, despite higher offset
- Consistent spacing demonstrates point-to-point reliability between all experiments
- May be acceptable for scaled-down precise operations, where all motion including effect of offsets is lessened

Future Work

- Determine minimum level of acceptable accuracy for desired tasks
- Study many devices to see how wear affects performance
- Better methods of stylus control for grid positioning
- Test across larger workspace with more verticality

d	θ	a	α
164.98mm	0	0	90°
0	0	133.35mm	0
0	0	0	90°
133.488mm	0	0	90°
0	-90°	0	-90°
-38.97mm	0	0	0

Fig 4. Original parameters from CAD in DH format.

d	θ	a	α
164.98mm	0	0	90°
0	0	**136.66mm**	0
0	0	0	90°
135.02mm	0	0	90°
0	-90°	0	-90°
-39.71mm	0	0	0

Fig 5. Optimized parameters in DH format, changes in bold.

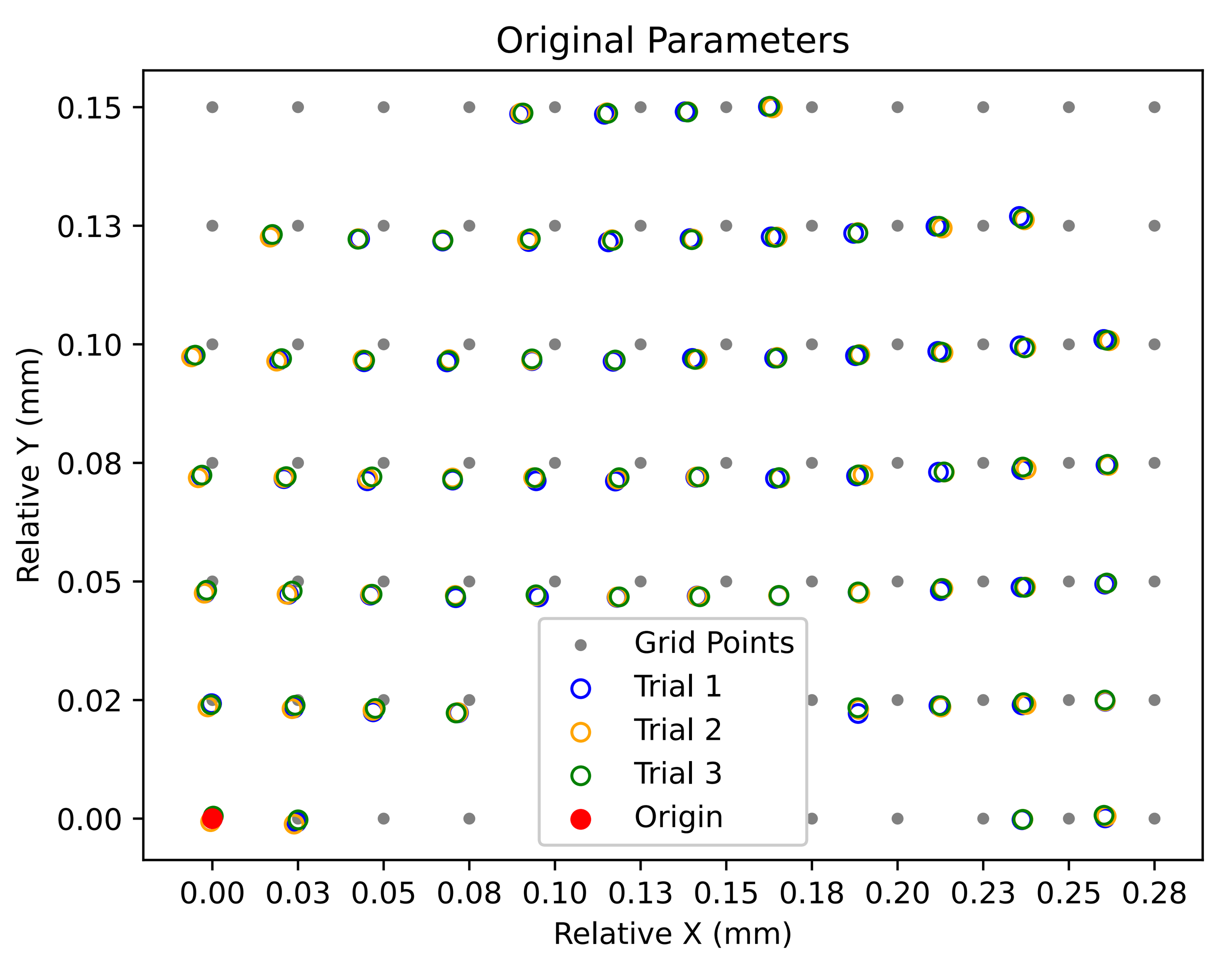

Fig 7. Point alignment from original parameters. Ideal grid positions as light grey dots, data points as colored circles.

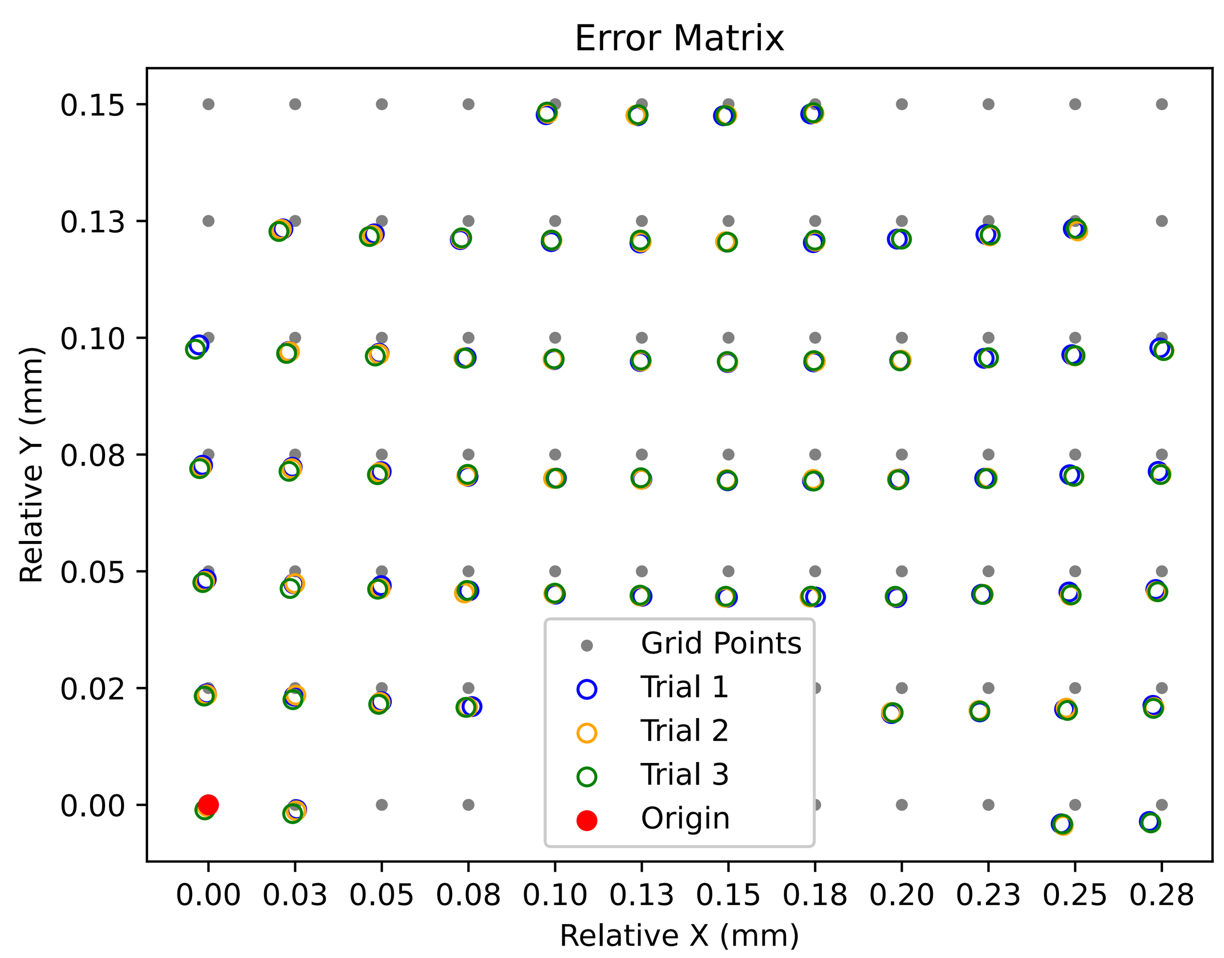

Fig 8. Point alignment from error matrix method. Notice the concave upwards "bend" in the center.

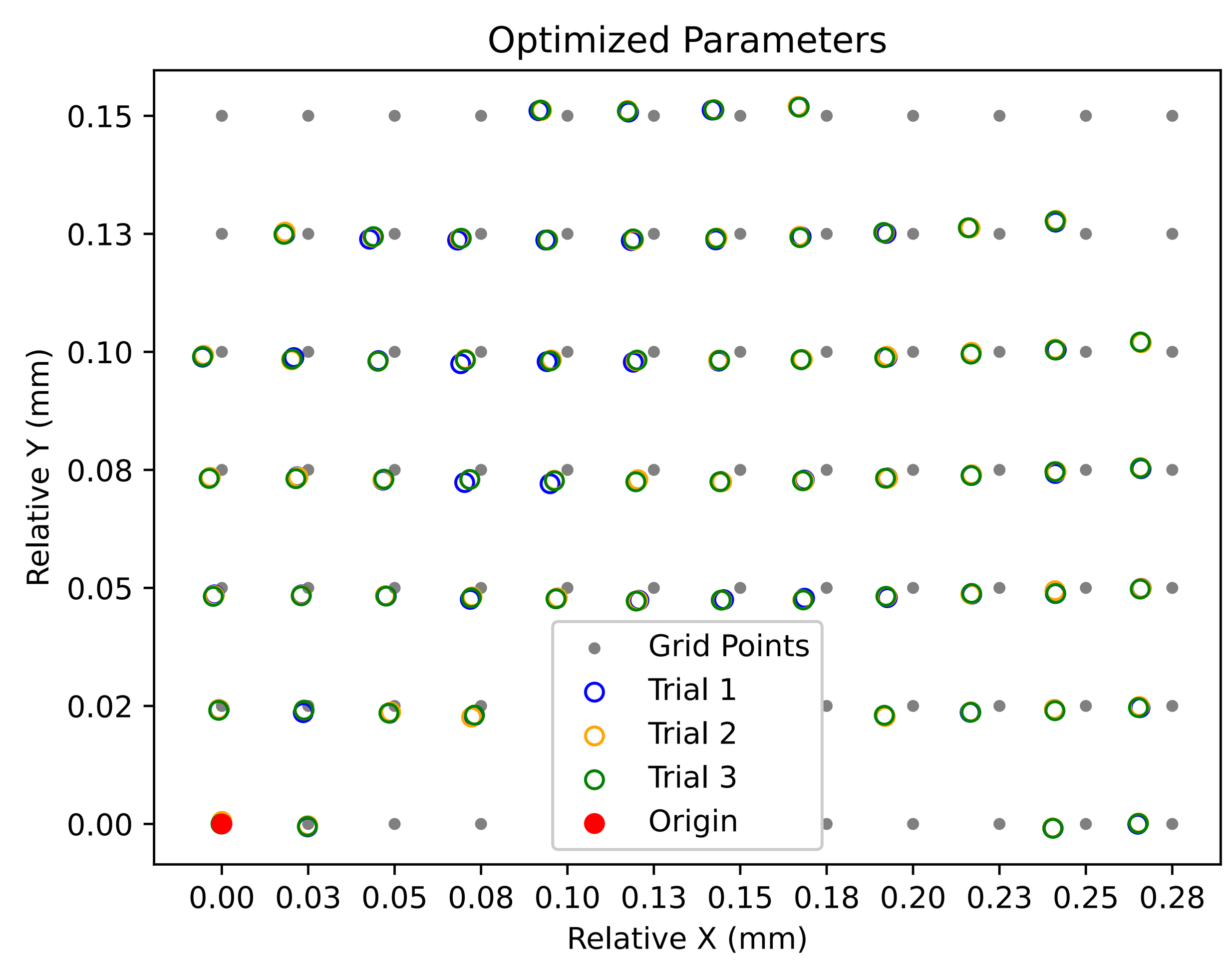

Fig 9. Point alignment for optimized parameters.