TUHH
Hamburg
University of
Technology

Documentation

Maximilian Neidhardt[2], Anton Reinecke[1], Antje Rogalla[1], Sascha Lehmann[1], Johanna Sprenger[2], Alexander Schlaefer[2], Sibylle Schupp[1]

Position Data of Offline Needle Steering

DOI: https://doi.org/10.15480/336.4544

Hamburg University of Technology (TUHH)
Institute for Software Systems[1] (STS) &
Institute of Medical Technology[2] (mtec)
21073 Hamburg

Contents

List of Figures

List of Tables

Offline Needle Steering 2D - Position Detection

1 Experimental Setup

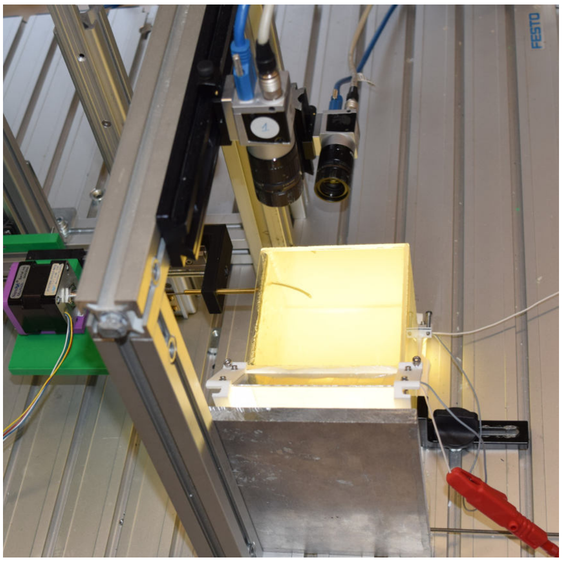

Figure 1.1: Setup-1

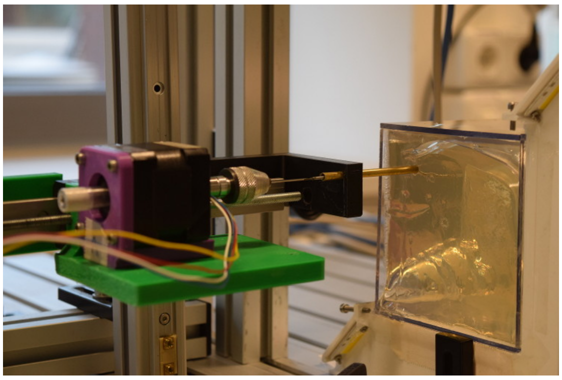

Figure 1.2: Setup-2

The experimental setup consists of a gelatin block of the size $10 \times 10 \times 10\ cm^3$ with a 10% gelatin to water concentration simulating a tissue phantom and a hollow shaft stepper motor controlling a flexible needle with a custom resin needle tip with a 45° inclination. The stepper motor moves forward, backward, or rotates with a needle velocity 0.7 mm/sec. Thanks to the needle's flexibility and sharpened tip, the needle moves in circles forwards and backward through the tissue. We can control the needle insertion direction by rotating the needle along the needle axis. This process we refer to as needle steering.

For tracking the needle movement, we fixed two cameras (Basler acA1300-200uc) at an angle of approximately 90 degrees to each other. We perform a camera calibration with a checkerboard to estimate the relative position between the two cameras and subsequently track the 3D position of the needle tip. Therefore, we embed a steel ball in the needle's clear epoxy tip and subsequently estimate the pixel position with standard image processing methods. Furthermore, a digital oscilloscope (Saleae, Logic Analyzer) records imaging and motor step triggers. Hence, we can map the estimated three-dimensional positions to the designated motor steps.

The experimental set up allows to detect reliable position data in a window of $5 \times 5 \times 5\ cm^3$ of the gelatin block.

2 Objectives

The experiments aim to detect position data traces of different needle movement scenarios to compare real needle movements with needle steering models and make statements about the accuracy of the models. Within the experiments, we execute different motion plans. One motion plan, for instance, is a forward push of the needle by 20 millimeters, then a rotation by 180 degrees, and another forward push by 20 millimeters. The following experiments present different executed motion plans and their recorded position data traces.

3 General Notes

We limit the experiments to a two-dimensional setting, but three-dimensional position data are recorded. Accordingly, we only execute motion plans with half rotations of 180 degrees. We do not execute motion plans with backward movement. Also, we do not allow more than two rotations within one motion plan.

Note, that the initial coordinates of the needle tip vary. During all experiments, we first align the needle so that with a forward push, the y-coordinate and z-coordinate of the needle decrease, and the x-coordinate does not change. Thus, assuming rotations of 180 degrees, the needle moves circularly through the y/z plane.

4 Description of Data

For each experiment, we record the feed of the needle in millimeters, the x, y, and z position of the needle in millimeters, and the rotation angle of the alignment of the sharpened needle tip in degrees. The setup allows the needle to be pushed forward and backward in the y direction, but in these experiments we only forward or rotate the needle.

The data we save in a csv file. See an excerpt of a needledata.csv below:

feed_mm	rot_deg	top_x_mm	tip_y_mm	tip_z_mm
11.244	180	141.9	31.427	158.91
11.356	180	141.87	31.188	158.8
...	...	...	...	...

The column feed_mm indicates the current feed rate of the needle. The column rot_deg indicates the current needle tip alignment. If rot_deg = 0, a forward push decreases the y-coordinate and z-coordinate of the needle, and the x-coordinate does not change. If rot_deg = 180, a forward push decreases the y-coordinate, increases the z-coordinate of the needle, and does not change the x-coordinate.

4.1 Exp. 2019/12/05

Implementation

On 2019/12/05 we forwarded the needle with no rotation.

Experiment	initial rotation in degrees	forward push in mm	rotation 1 in degrees	forward push after rotation 1
No_Rot_1	180	42.252	-	-
No_Rot_2	0	72	-	-

Table 4.1: Motion plans 2019/12/15

Visualizations

No_Rot_1

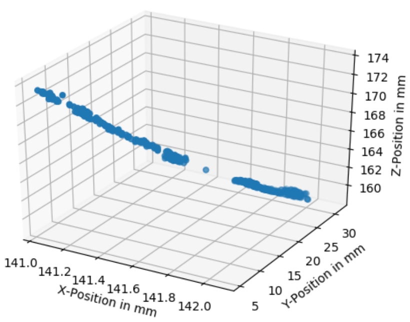

Figure 4.3: No_Rot_1_trace

No_Rot_2

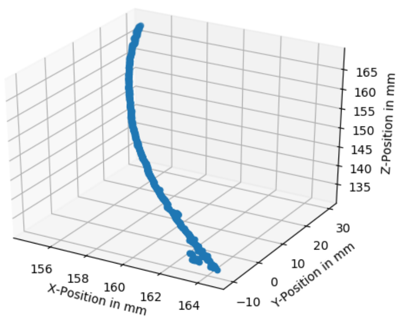

Figure 4.4: No_Rot_2_trace

4.2 Exp. 2020/01/15

Implementation

In the experiments on 2020/01/15, we executed the motion plans given in table 4.2.

Exp.	init. rot. in deg.	forw. push in mm	rot. 1 in deg.	forw. push after rot. 1	rot. 2 in deg.	forw. push after rot. 2
No_Rot_3	0	6.944	180	19.774	-	-
One_Rot_1	0	14.862	180	12.360	-	-
One_Rot_2	0	9.924	180	14.446	-	-
One_Rot_3	0	6.511	180	19.806	-	-
Two_Rot_2	0	4.959	180	19.619	180	0.992
Two_Rot_3	0	12.889	180	9.763	180	3.806
Bad_1	0	7.820	180	19.645	180	21.692
Bad_2	0	7.942	180	2.549	180	11.879

Table 4.2: Motion plans 2020/01/15

For the experiments, we use the same notion as in our publication, the MARS 2020 Paper [1]. In the MARS 2020 paper, the data of *No_Rot_3* was mistakenly interpreted as a trace without rotations.

Visualizations

No_Rot_3

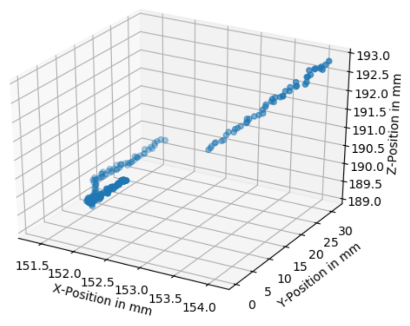

Figure 4.5: No_Rot_3_trace

One_Rot_1

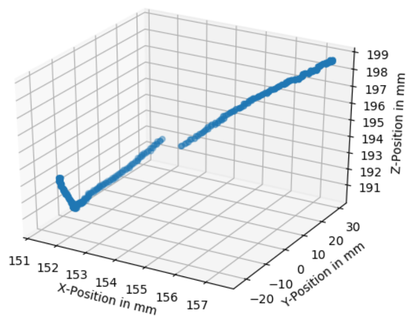

Figure 4.6: One_Rot_1_trace

One_Rot_2

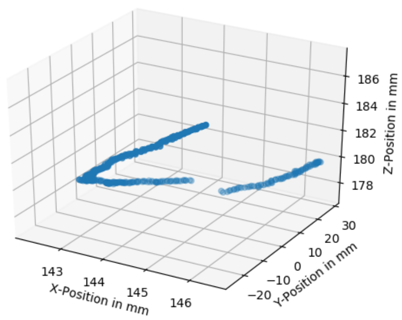

Figure 4.7: One_Rot_2_trace

Two_Rot_2

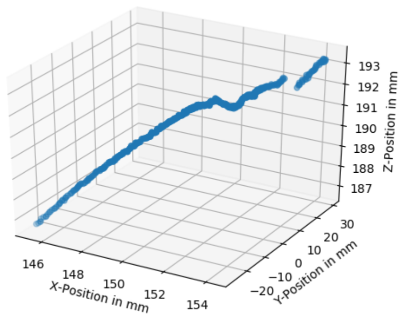

Figure 4.8: Two_Rot_2_trace

Two_Rot_3

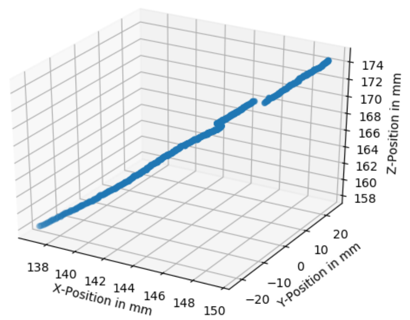

Figure 4.9: Two_Rot_3_trace

One_Rot_3

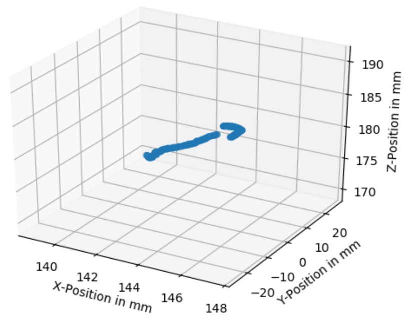

Figure 4.10: One_Rot_3_trace

Bad_1

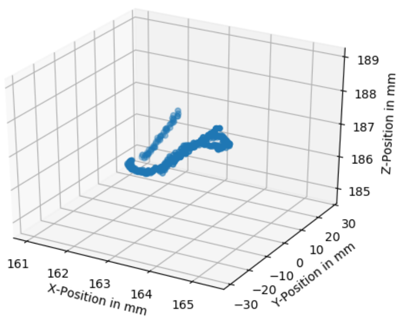

Figure 4.11: Bad_1_trace

Bad_2

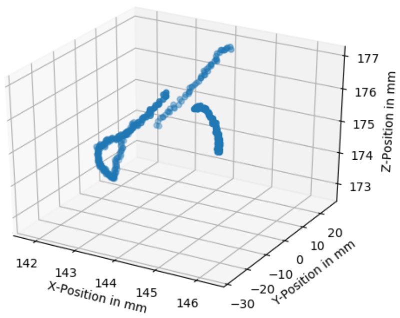

Figure 4.12: Bad_2_trace

4.3 Exp. 2020/01/17

Implementation

In the experiments on 2020/01/17, we executed the motion plans given in table 4.3.

Exp.	init. rot. in deg.	forw. push in mm	rot. 1 in deg.	forw. push after rot. 1	rot. 2 in deg.	forw. push after rot. 2
Tow_Rot_1	0	9.945	180	11.369	180	14.206

Table 4.3: Motion plans 2020/01/17

Visualizations

Tow_Rot_1

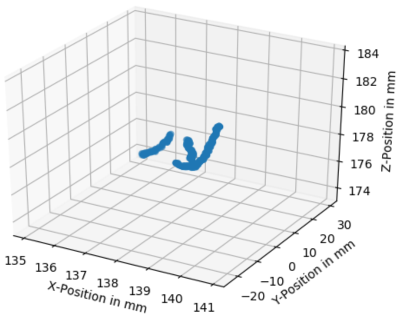

Figure 4.13: Tow_Rot_1_trace

5 Challenges

We noticed that the initial actual needle tip angle differs between the experiments. Due to the inhomogeneity of the tissue, we do not know this angle in advance, which makes an exact path planning based on the given information about the needle impossible. For path planning using a needle steering model, we propose a practical preprocessing step of pushing the needle 5 mm forward into the gelatin to detect the needle tip angle and start position of the single experiment and initialize the needle steering model, respectively.

Bibliography

[1] Antje Rogalla, Sascha Lehmann, Maximilian Neidhardt, Johanna Sprenger, Marcel Bengs, Alexander Schlaefer, and Sibylle Schupp. "Synthesizing Strategies for Needle Steering in Gelatin Phantoms". In: *Electronic Proceedings in Theoretical Computer Science*. Vol. 316. Open Publishing Association, Apr. 2020, pp. 261–274. DOI: 10.4204/eptcs.316.10.