

Gesture Recognition Using Chipless RFID Tag Held in Hand

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Outline

- Motivation
- Principle of Operation
- Measurements and Gesture Recognition
- Video Demonstrations
- Conclusions

Motivation For Gesture Recognition

- Gaming
- Sign language
- Virtual manipulation
- Daily assistance
- Palm verification
- Human robot interaction

Meta Oculus Quest Hand Tracking



- If hands are hidden ?
- In bad light conditions ?

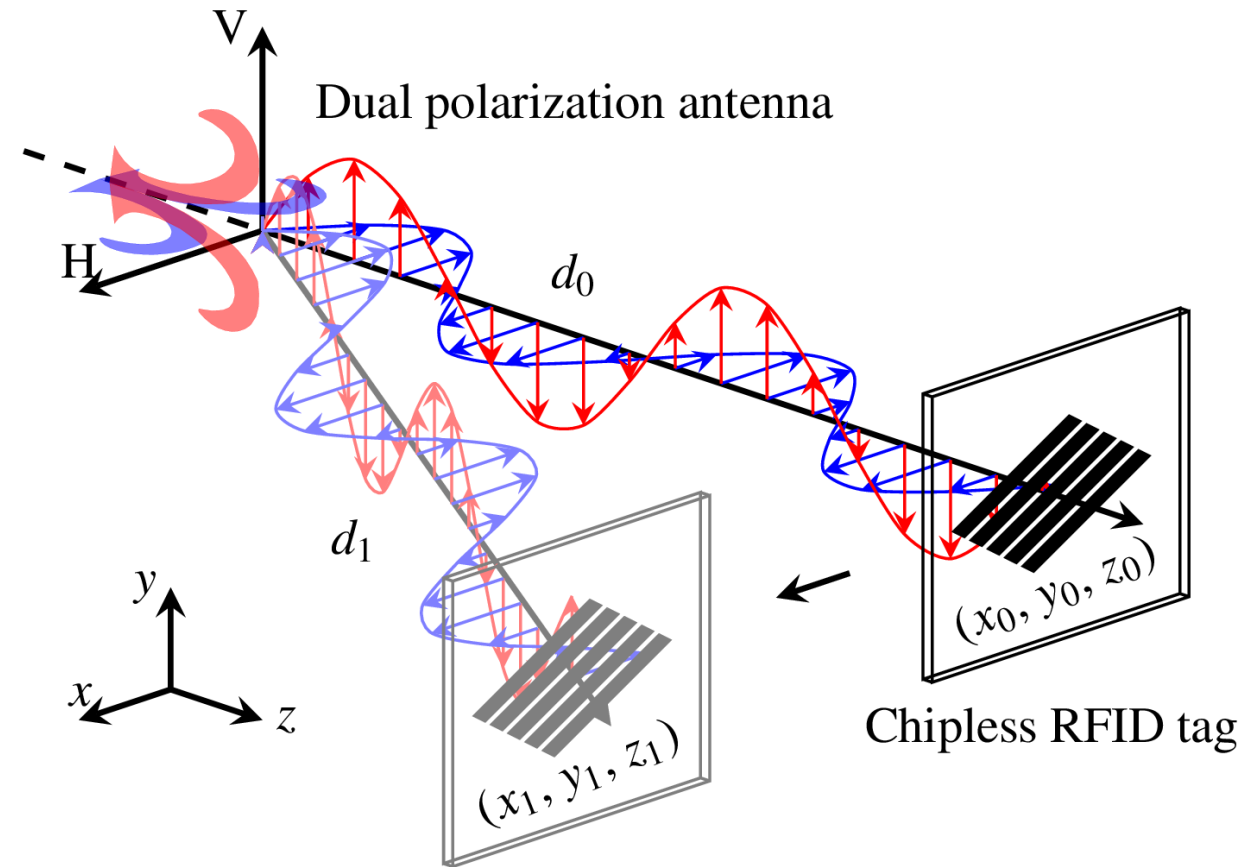
Principle of Operation

Mathematical model

$$\Delta d = d_1 - d_0 = -\frac{1}{2k} \arg \left(\frac{M_{VH}^{d_1}}{M_{VH}^{d_0}} \right) \quad (1)$$

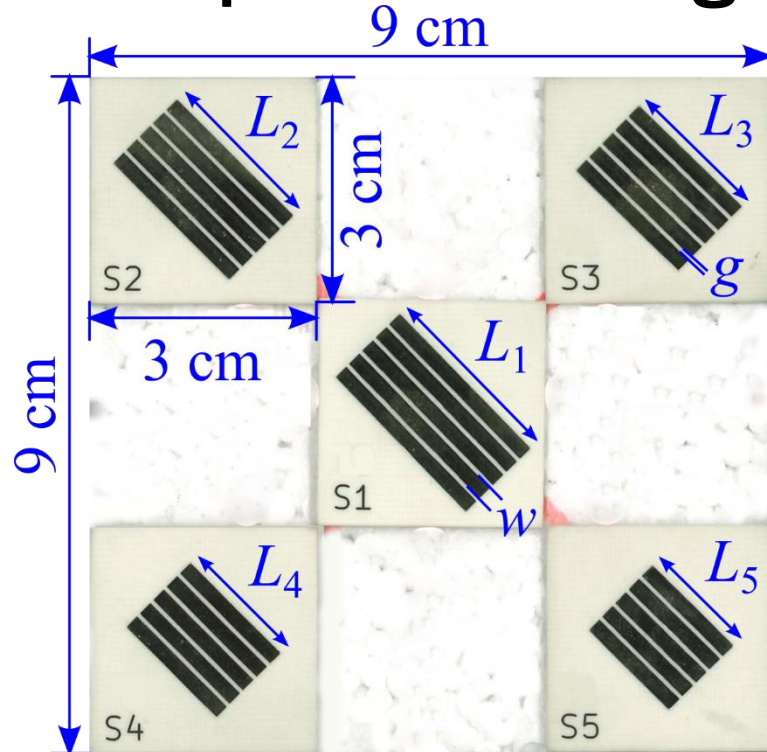
where

- $k = 2\pi/\lambda$,
- $M_{VH}^{d_0} = S_{VH}^{d_0} - I_{VH}$,
- $M_{VH}^{d_1} = S_{VH}^{d_1} - I_{VH}$.
- $S_{VH}^{d_0}$ correspond to tag signal at d_0 ,
- $S_{VH}^{d_1}$ correspond to tag signal at d_1 ,
- I_{VH} correspond to clutter.



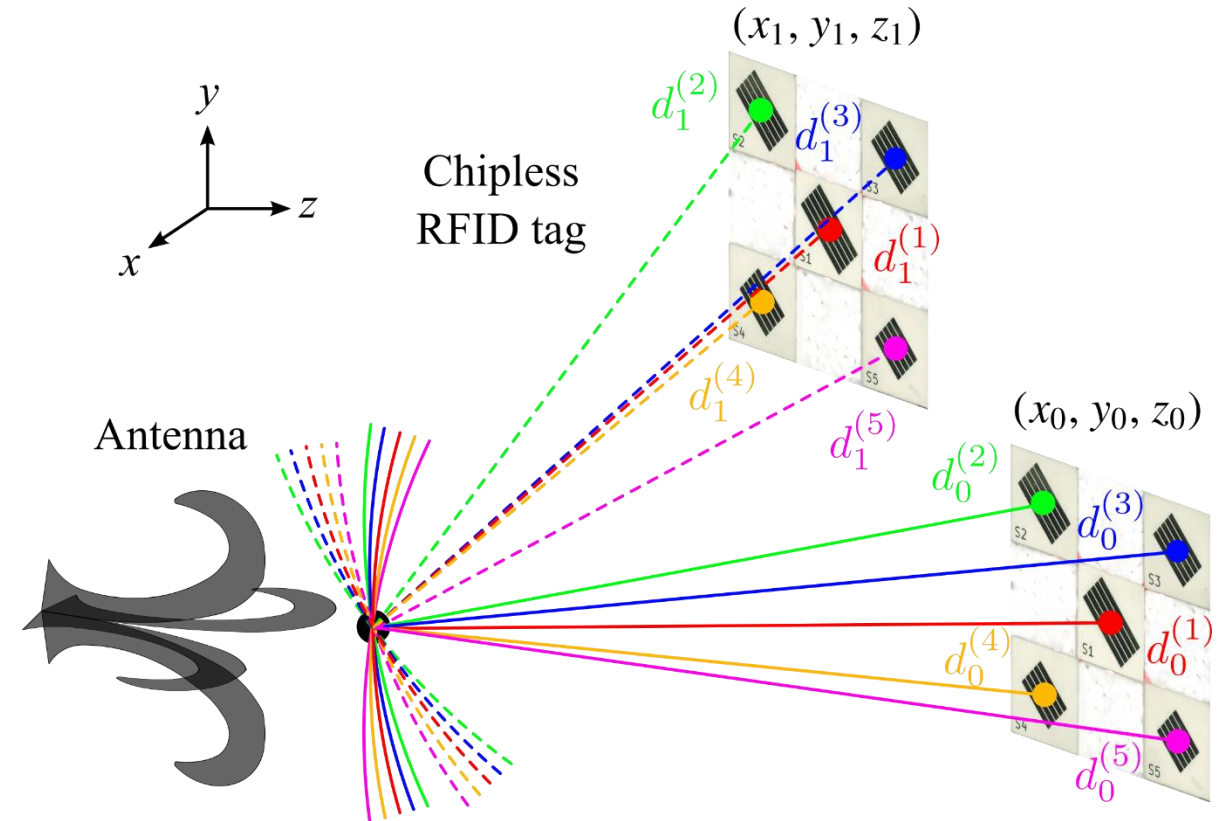
Principle of Operation

Chipless RFID tag



$L_1 = 24.8$ mm, $L_2 = 21.8$ mm, $L_3 = 19$ mm, $L_4 = 16.8$ mm, $L_5 = 15$ mm, $w = 2$ mm, $g = 0.5$ mm, and $r = 4.24$ cm.

Multilateration



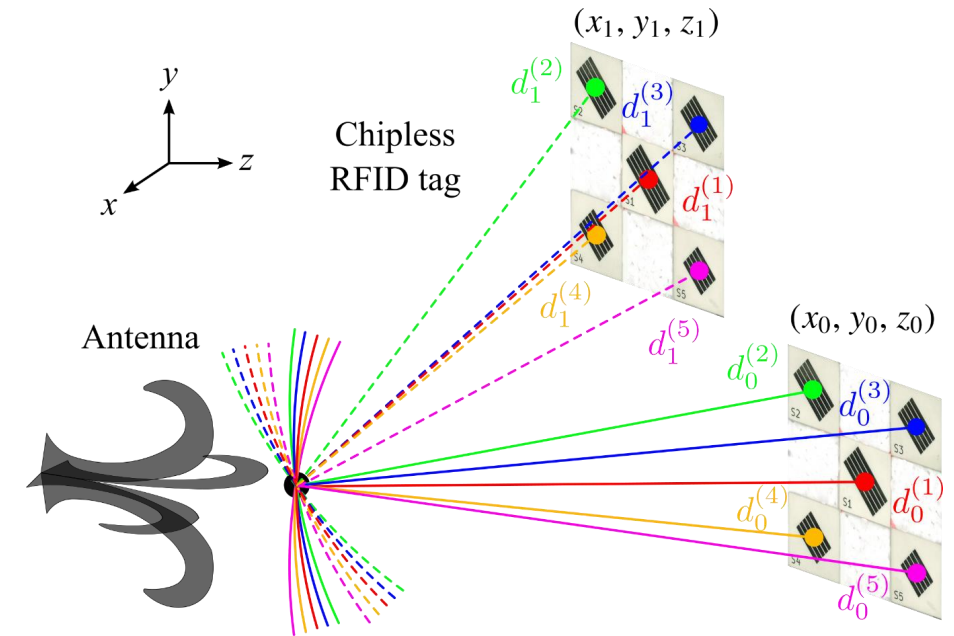
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Principle of Operation

Multilateration

$$\begin{cases} \hat{d}_1 = \sqrt{(x + x_{s1} + x_A)^2 + (y + y_{s1} + y_A)^2 + (z + z_{s1} + z_A)^2} \\ \hat{d}_2 = \sqrt{(x + x_{s2} + x_A)^2 + (y + y_{s2} + y_A)^2 + (z + z_{s2} + z_A)^2} \\ \vdots \\ \hat{d}_8 = \sqrt{(x + x_{s8} + x_A)^2 + (y + y_{s8} + y_A)^2 + (z + z_{s8} + z_A)^2} \end{cases}, \quad (2)$$

$$\langle \hat{x}, \hat{y}, \hat{z} \rangle = \arg \min \sum_{i=1}^5 (\hat{d}_i - d_{ci})^2, \quad (3)$$



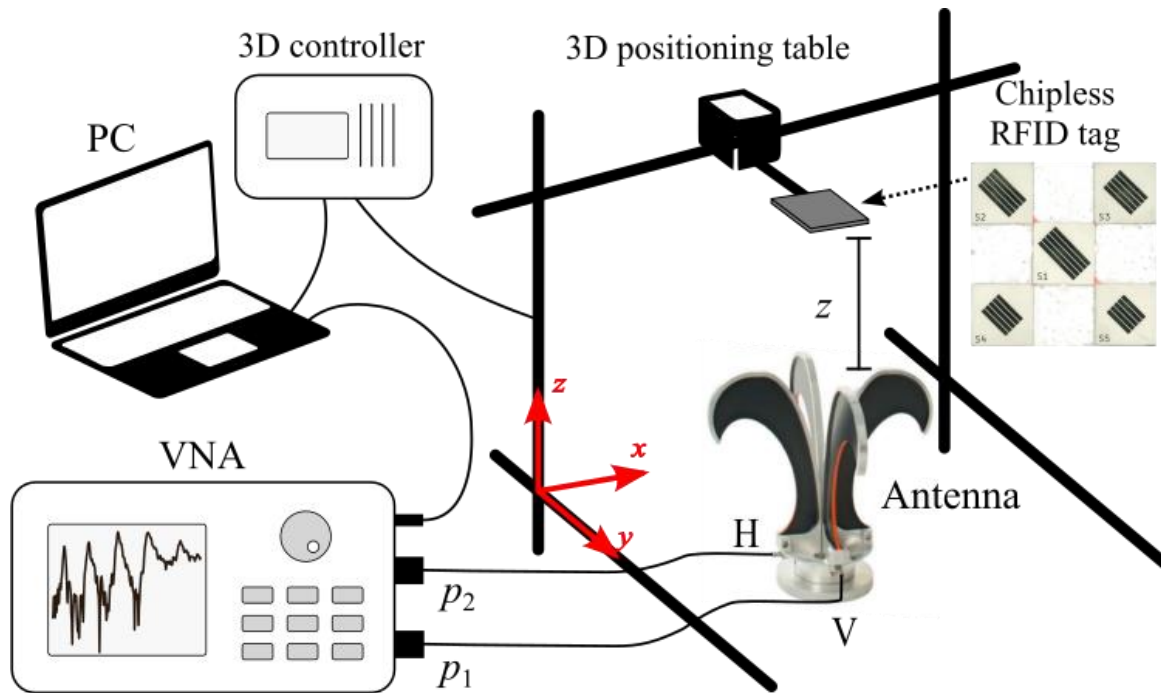
Principle of Operation

Algorithm 1: 3D localization.

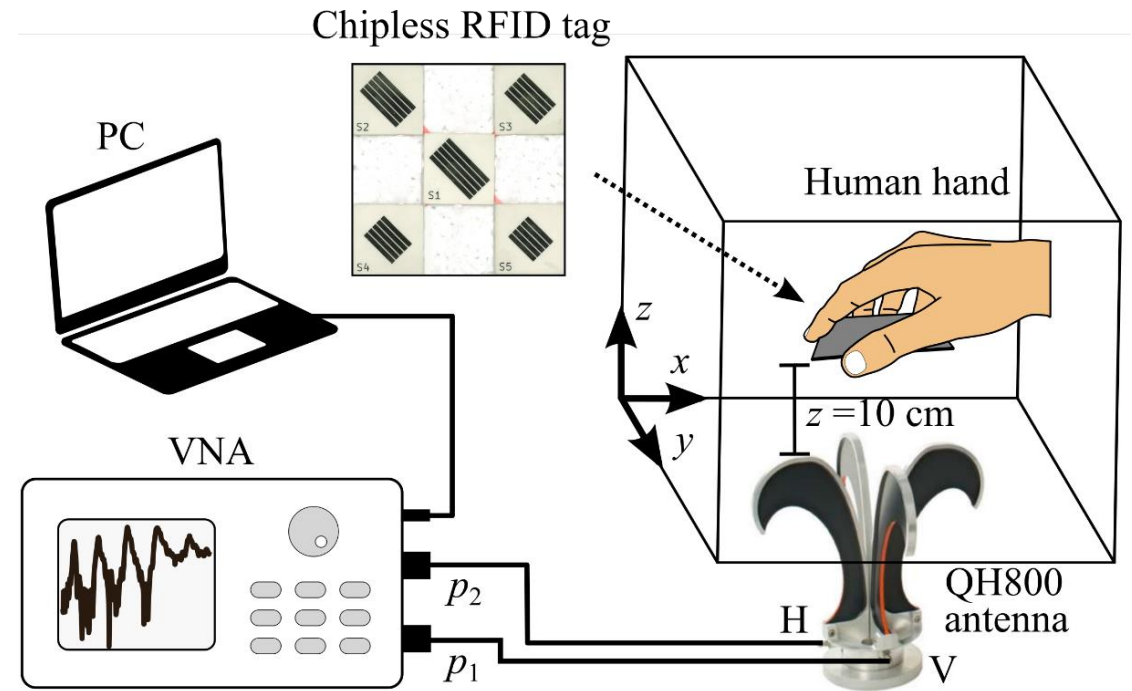
```
1 Initialization: phase correction  $\phi_c^i = 0$  at  $(x_0, y_0, z_0)$ 
2 Acquisition of signals:  $S_{vh}^{d^{(i)}}(f_i)$ , and  $I_{vh}(f_i)$ 
3 while  $j = 1$  to  $acquisition = True$  do
4     Acquisition of signal:  $S_{vh}^{d_j^{(i)}}(f_i)$ 
5     for  $i = 1$  to  $i = 5$  do
6         Extraction of  $\phi_j^{(i)}$  using (1)
7          $\Delta\phi^{(i)} = \phi_j^{(i)} - \phi_{j-1}^{(i)}$ 
8         if  $\Delta\phi^{(i)} > \pi$  then
9              $\phi_c^{(i)} = \phi_c^{(i)} - 2\pi$ 
10        else if  $\Delta\phi^{(i)} < \pi$  then
11             $\phi_c^{(i)} = \phi_c^{(i)} + 2\pi$ 
12         $\phi_j^{(i)} \leftarrow \phi_j^{(i)} + \phi_c^{(i)}$ 
13    Calculation of  $\Delta d_j^{(i)}$  from (1)
14    Multilateration by solving (2)
15    Estimation of  $(x_j, y_j, z_j)$  by (3)
```

Measurement Setups

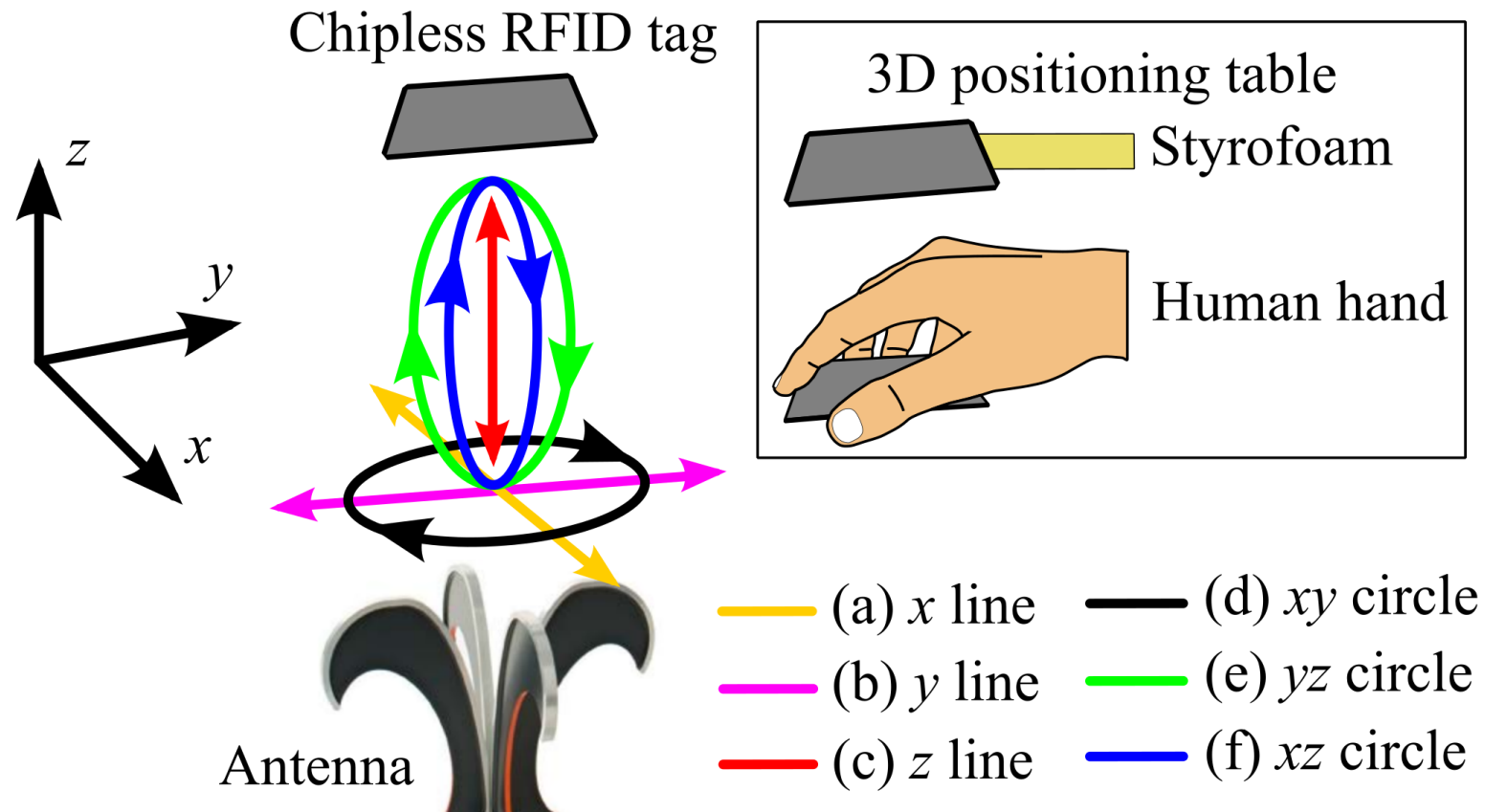
3D positioning table



Human hand

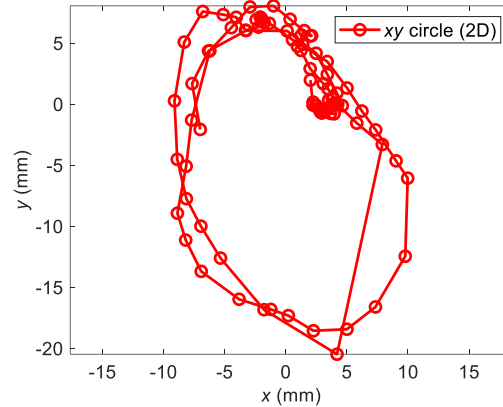


Ideal Gestures Trajectories

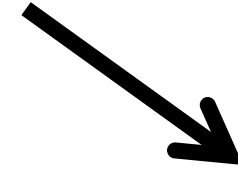
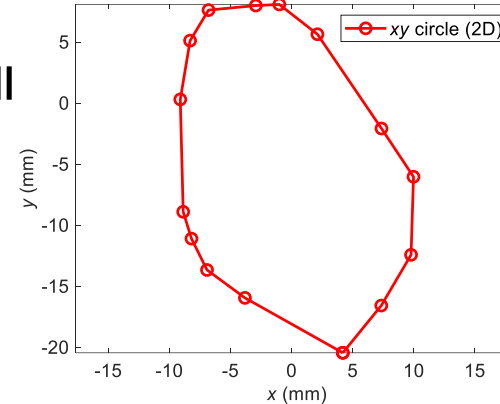


Similarity Metric

Measured trajectory



Convex hull



Turning distance = 0

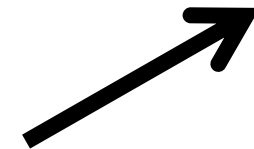
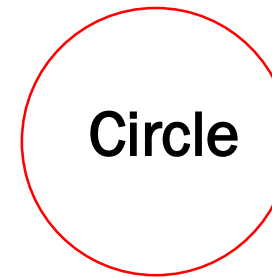
- Convex hull

- Turning distance

- Compares polygons
- Regardless of rotation or scaling

$$d_p = \left(\min_{\theta \in \mathbb{R}} \int_0^1 |\Theta_A(s+t) - \Theta_B(s) + \theta|^p ds \right)^{\frac{1}{p}}, \quad (4)$$

Ideal geometry

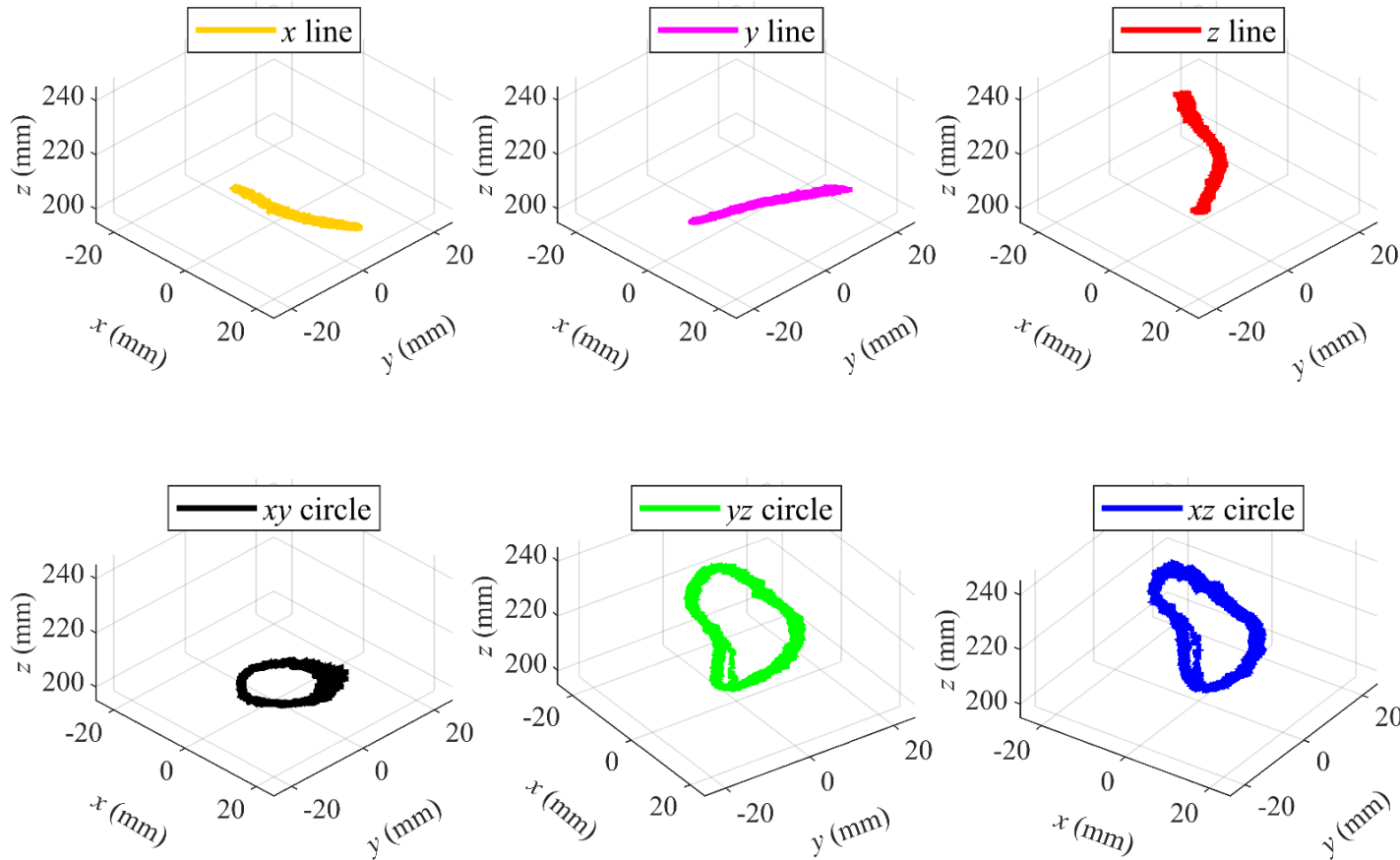


E. Arkin, L. Chew, D. Huttenlocher, K. Kedem, and J. Mitchell, "An efficiently computable metric for comparing polygonal shapes," IEEE Trans. Pattern Anal. Mach. Intell., vol. 13, no. 3, pp. 209–216, 1991.

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Measurements (3D Table)

50 measured trajectories



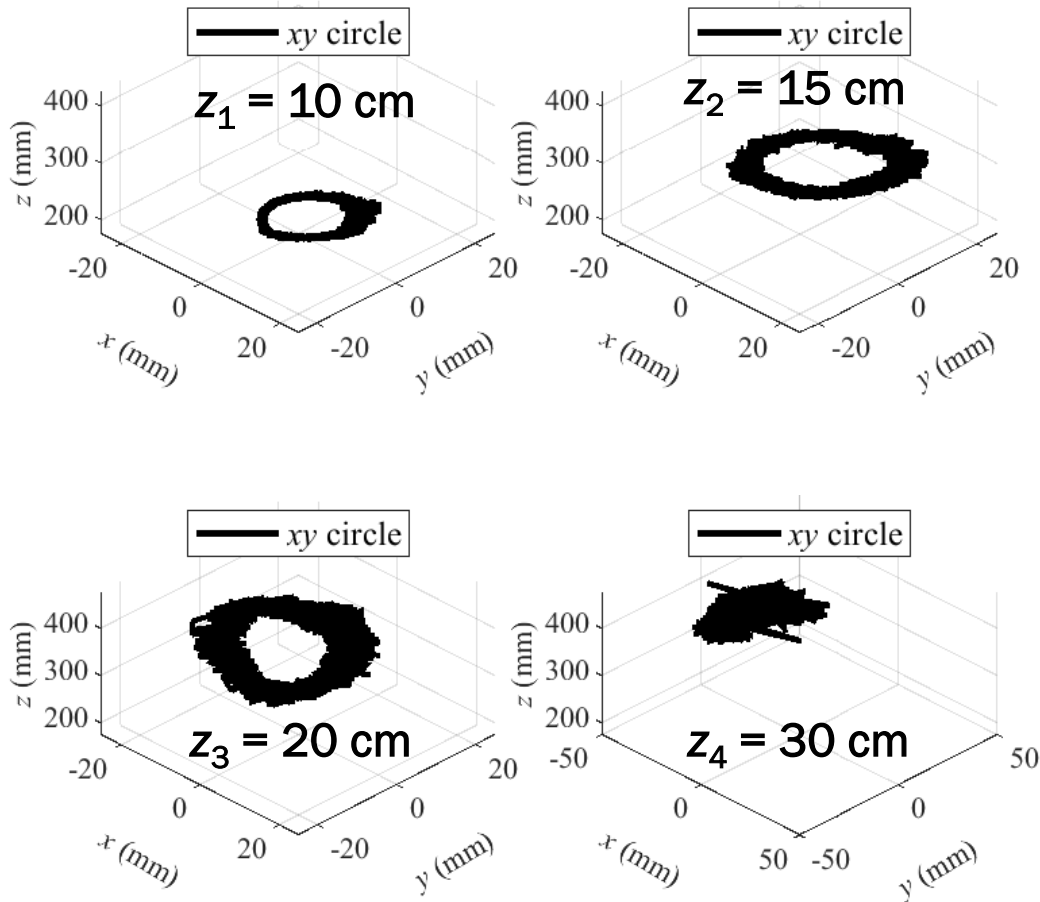
Confusion matrix

Estimated gesture	<i>x</i> line	100.0% 50	0.0% 0	0.0% 0	0.0% 0	0.0% 0	0.0% 0
	<i>y</i> line	0.0% 0	92.0% 46	0.0% 0	0.0% 0	0.0% 0	0.0% 0
	<i>z</i> line	0.0% 0	0.0% 0	100.0% 50	0.0% 0	0.0% 0	8.0% 4
	<i>xy</i> circle	0.0% 0	8.0% 4	0.0% 0	100.0% 50	0.0% 0	0.0% 0
	<i>yz</i> circle	0.0% 0	0.0% 0	0.0% 0	0.0% 0	100.0% 50	0.0% 0
	<i>xz</i> circle	0.0% 0	0.0% 0	0.0% 0	0.0% 0	0.0% 0	92.0% 46
			<i>x</i> line	<i>y</i> line	<i>z</i> line	<i>xy</i> circle	<i>yz</i> circle
Actual gesture							

Overall accuracy = 97.33%

Measurements (3D Table)

50 measured trajectories



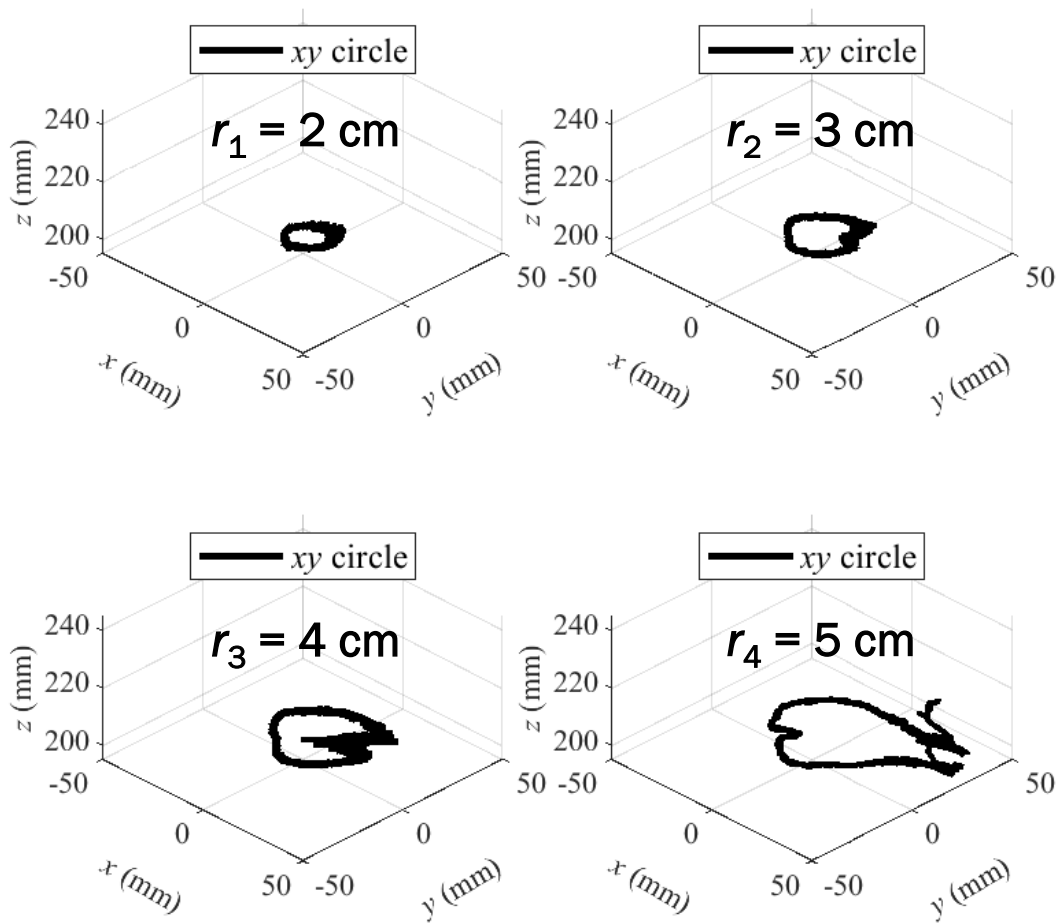
Confusion matrix

Estimated gesture	xy circle z_1	xy circle z_2	xy circle z_3	xy circle z_4	other
xy circle z_1	100.0% 50	0.0% 0	0.0% 0	0.0% 0	0.0% 0
xy circle z_2	0.0% 0	100.0% 50	0.0% 0	0.0% 0	0.0% 0
xy circle z_3	0.0% 0	0.0% 0	100.0% 50	0.0% 0	0.0% 0
xy circle z_4	0.0% 0	0.0% 0	0.0% 0	70.0% 35	0.0% 0
other	0.0% 0	0.0% 0	0.0% 0	30.0% 15	0.0% 0
	xy circle z_1	xy circle z_2	xy circle z_3	xy circle z_4	other
	Actual gesture				

Overall accuracy = 92.50%

Measurements (3D Table)

50 measured trajectories



Confusion matrix

Estimated gesture	$xy\text{ circle } r_1$	$xy\text{ circle } r_2$	$xy\text{ circle } r_3$	$xy\text{ circle } r_4$	other
$xy\text{ circle } r_1$	100.0% 50	0.0% 0	0.0% 0	0.0% 0	0.0% 0
$xy\text{ circle } r_2$	0.0% 0	100.0% 50	0.0% 0	0.0% 0	0.0% 0
$xy\text{ circle } r_3$	0.0% 0	0.0% 0	98.0% 49	0.0% 0	0.0% 0
$xy\text{ circle } r_4$	0.0% 0	0.0% 0	0.0% 0	22.0% 11	0.0% 0
other	0.0% 0	0.0% 0	2.0% 1	78.0% 39	0.0% 0
	$xy\text{ circle } r_1$	$xy\text{ circle } r_2$	$xy\text{ circle } r_3$	$xy\text{ circle } r_4$	other
Actual gesture					

Overall accuracy = 80%

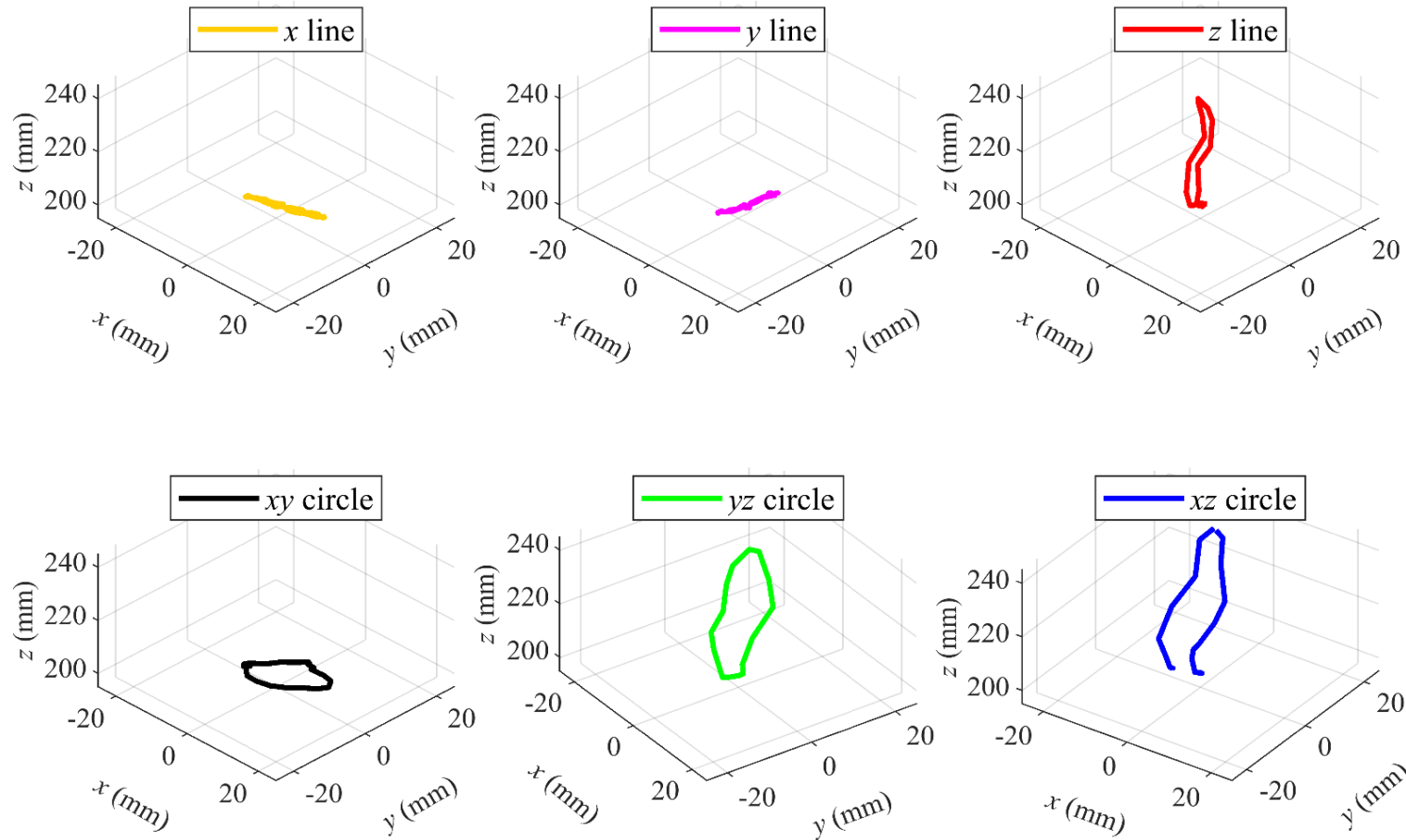
Video Demonstration (3D Table)

Measurement Setup

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Measurements (Human Hand)

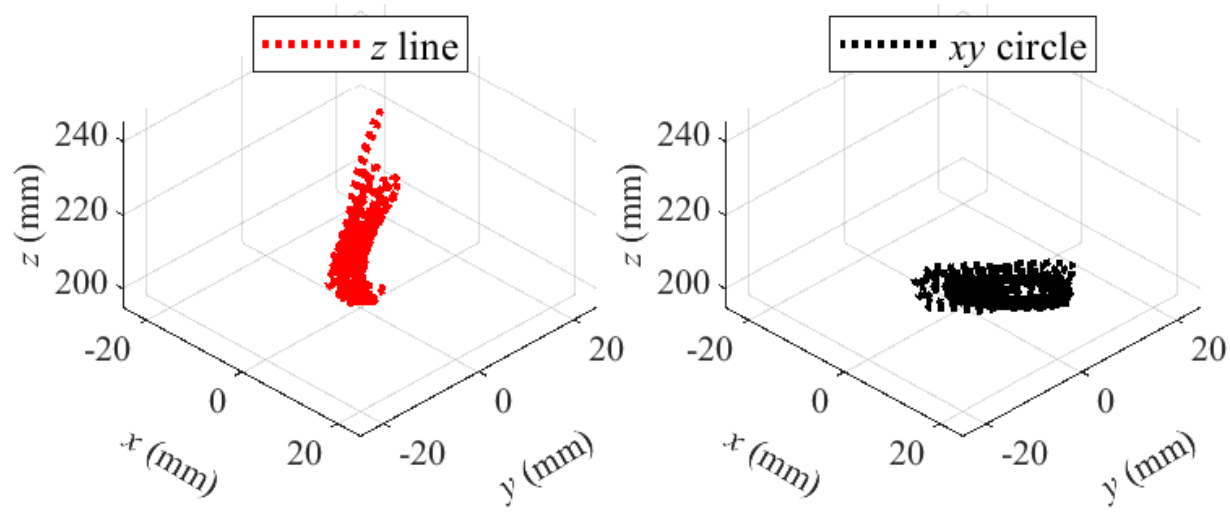
Measured trajectories



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Measurements (Human Hand)

20 measured trajectories



Confusion matrix

Estimated gesture	Actual gesture		
	z line	xy circle	other
	95.0% 19	0.0% 0	0.0% 0
xy circle	0.0% 0	95.0% 19	0.0% 0
other	5.0% 1	5.0% 1	0.0% 0

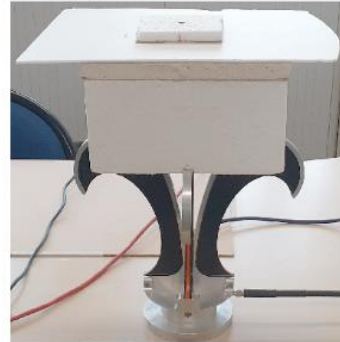
Overall accuracy = 95%

Measurements (Human Hand)

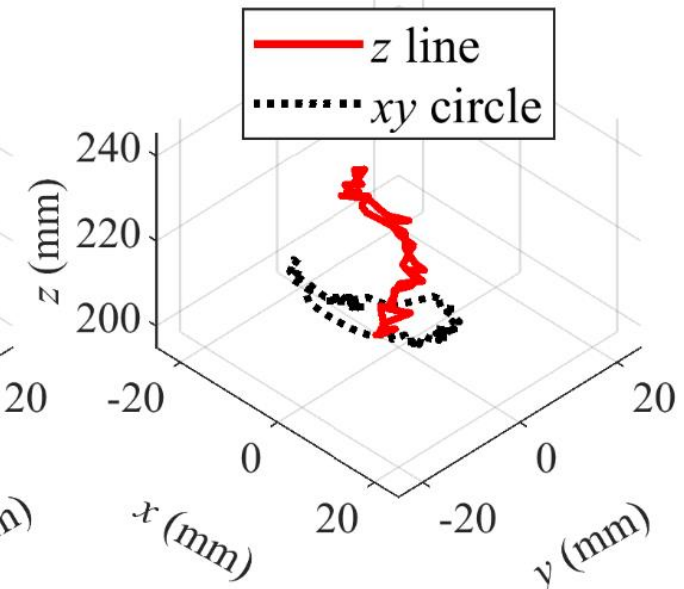
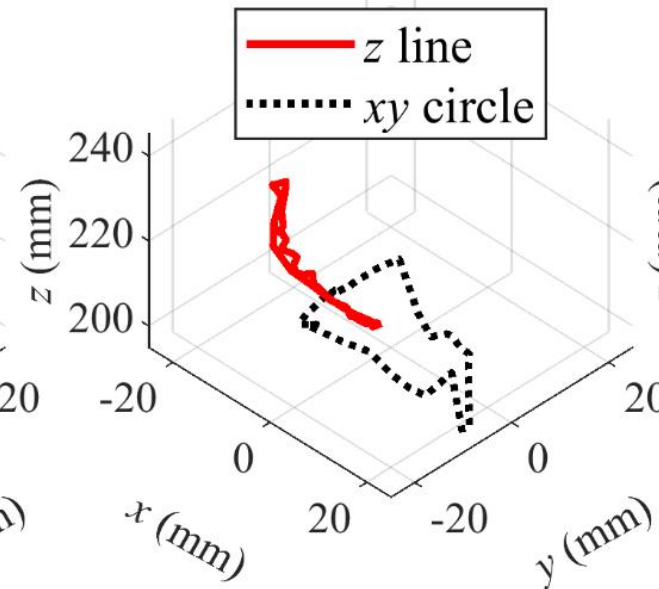
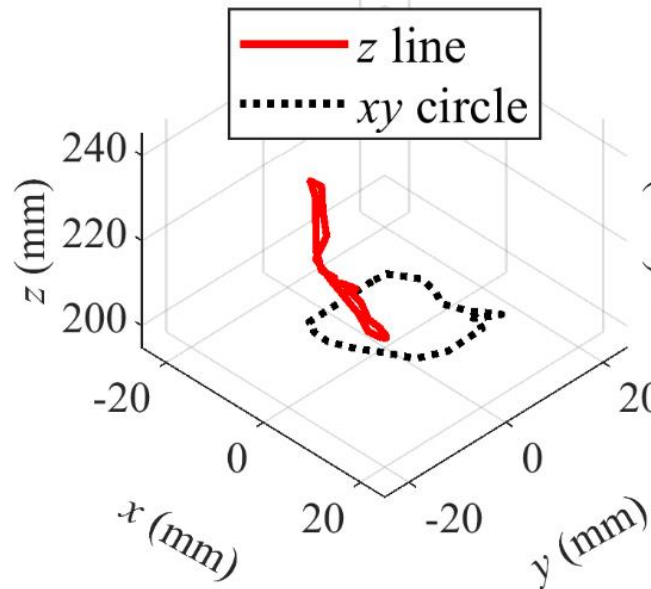
Wooden board



Gypsum board



Chipboard



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Video Demonstration (Human Hand)

Measurement Setup

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Conclusions

- Proposed gesture recognition
 - Model based
 - Real time
 - Works within a 3D volume of $10 \times 10 \times 10 \text{ cm}^3$
 - Works under the objects
- Other possible features
 - Chipless RFID functionalities
 - 3D computer mouse

Thank You

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Questions



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