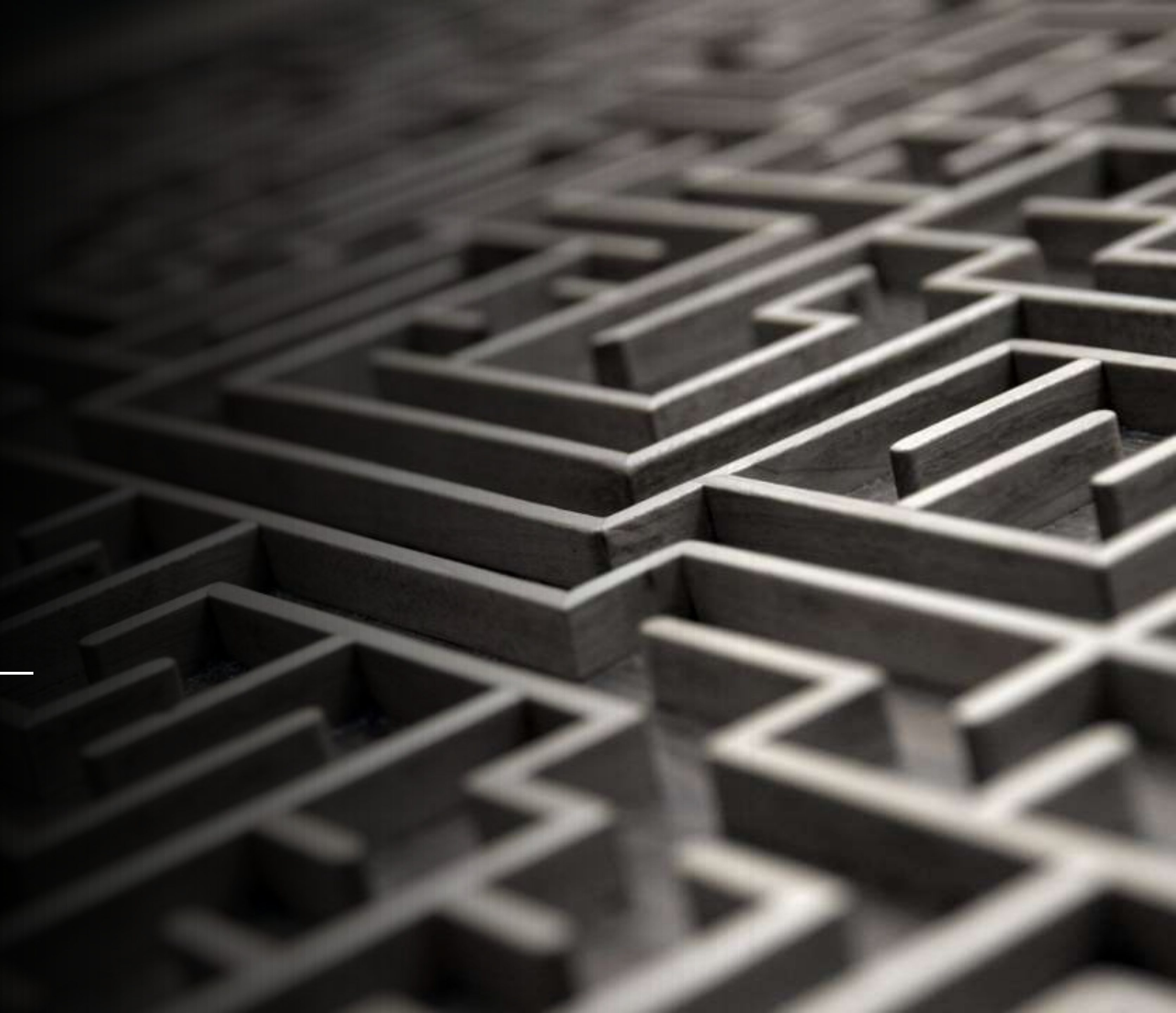
Investigating Hyperacuity and Navigation with Haptic Belts

Julian Vallyeason

Brown University



Introduction

Navigational Technologies Considerations

1. Possible intrusion into the existing capacity of a sensory node
2. Difficulty in distilling visual feedback into low-complexity data without information loss
3. Developing an encoding scheme that can be reliably learned and continuously provides sensory feedback

[1] https://thebark.com/content/raising-guide-dog-puppy
[2] https://brailleworks.com/free-white-cane/

Motivating Literature

•*Johannesson et al.*

- Spatial tactile acuity of motors retained at distances as close as 13 mm apart
- 92% accuracy for separations of 30 mm

Johannesson, O. I., Hoffmann, R., Valgeirsdottir, V. V., Unnoorsson, R., Moldoveanu, A., & Kristjonsson, .. (2017). Relative vibrotactile spatial acuity of the torso. Experimental brain research, 235(11), 3505–3515. https://doi.org/10.1007/s00221-017-5073-6

•*Cholewiak et al.*

- Examined detection threshold for vibration on 12 sites around the abdomen
- People tend to interpret vibrations ‘relative to specific loci around the body’ (spine & navel)

Cholewiak, Roger W., et al. “Vibrotactile Localization on the Abdomen: Effects of Place and Space.” Perception & Psychophysics, vol. 66, no. 6, 2004, pp. 970–987., doi:10.3758/bf03194989.

•*Pielot et al.*

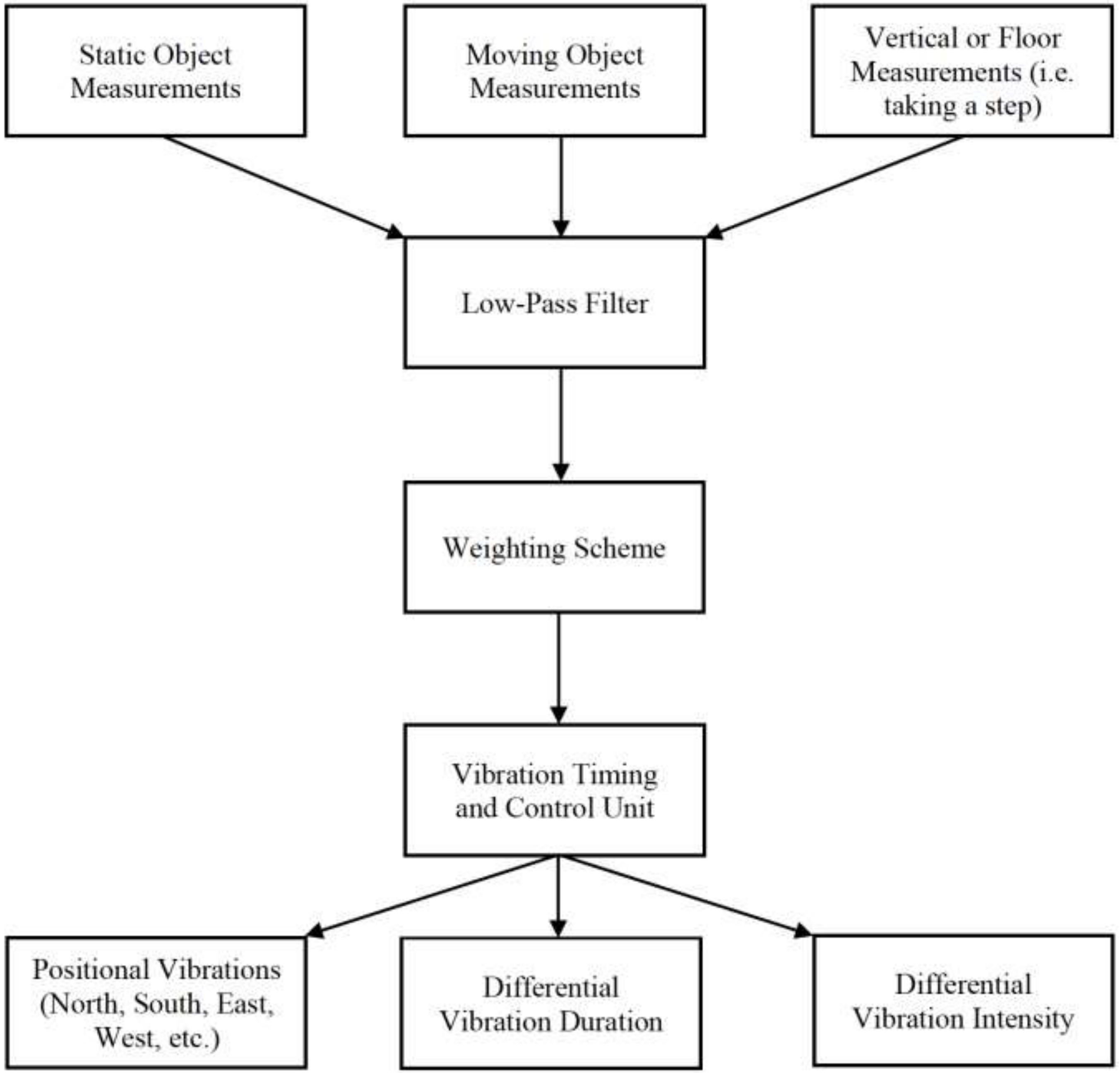
- Individuals can interpolate vibrations of different intensities around their waist

Pielot, Martin, et al. “Evaluation of Continuous Direction Encoding with Tactile Belts.” Haptic and Audio Interaction Design Lecture Notes in Computer Science, 2008, pp. 1–10., doi:10.1007/978-3-540-87883-4_1.

Objective

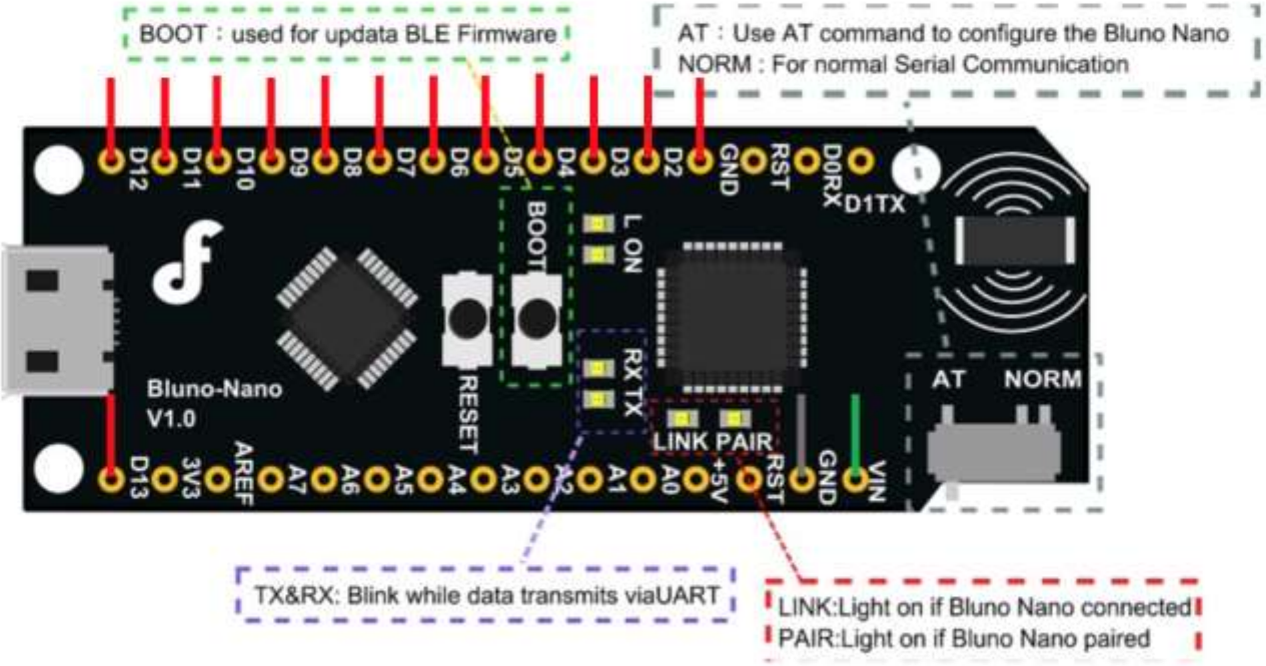
- Investigate the effect of haptic belt motor density and vibration strength on vibratory perception of direction
- Examine the efficiency of single-motor vs. vibrating a distribution of motors at varying intensities
- How are vibratory perceptions translated into directions and navigation?

Test 1: Vibratory Perception
Test 2: Discrete Control
Test 3: Continuous Feedback



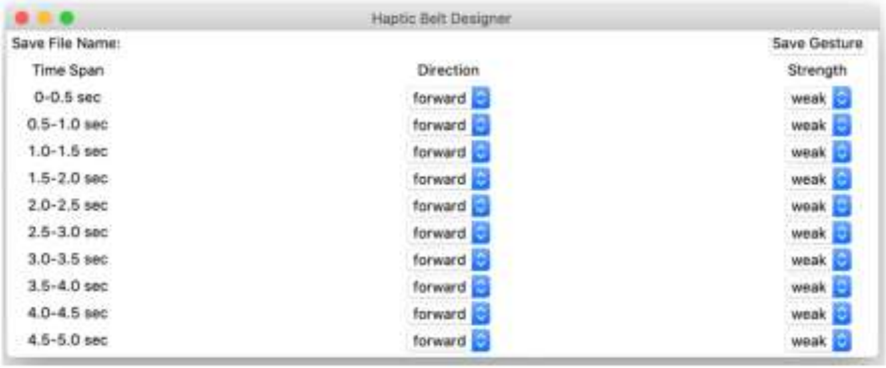
Adapted from; Katzschmann, R. K., Araki, B., & Rus, D. (2018). Safe Local Navigation for Visually Impaired Users with a Time-of-Flight and Haptic Feedback Device. IEEE Transactions on Neural Systems and Rehabilitation Engineering, 26 (3), 583–593. doi: 10.1109/tnsre.2018.2800665

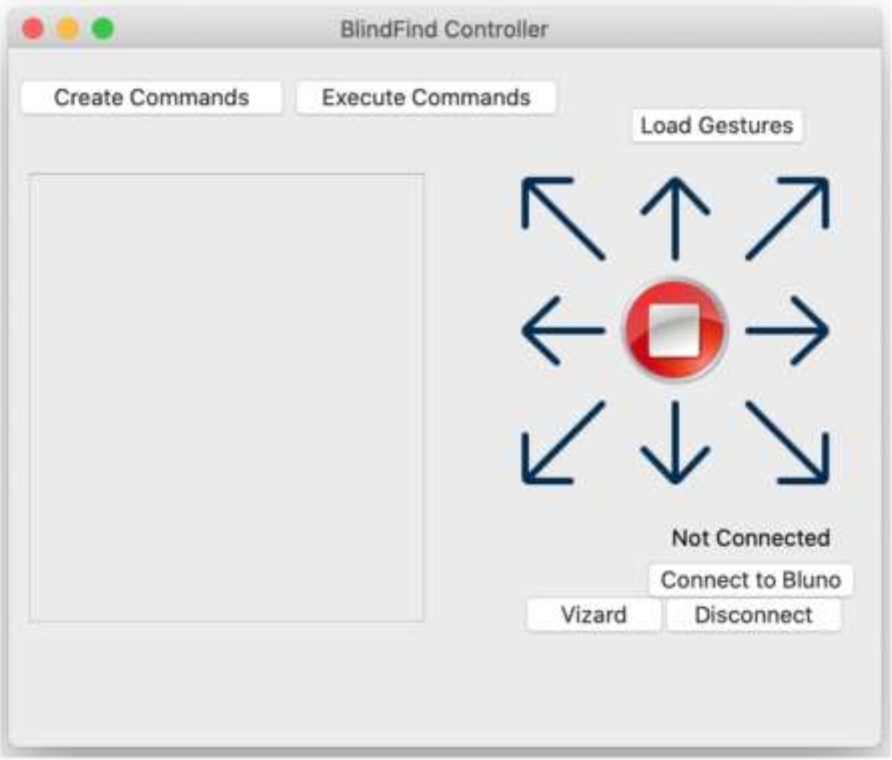
Materials


BOOT：used for updata BLE Firmware
AT：Use AT command to configure the Bluno Nano
NORM : For normal Serial Communication
D12 D11 D10 D9 D8 D7 D6 D5 D4 D3 D2 GND RST D0RX D1TX
BOOT
L ON
Bluno-Nano
V1.0
RESET
RX TX
LINK PAIR
AT NORM
D13 3V3 AREF A7 A6 A5 A4 A3 A2 A1 A0 +5V RST GND VIN
TX&RX: Blink while data transmits viaUART
LINK:Light on if Bluno Nano connected
PAIR:Light on if Bluno Nano paired

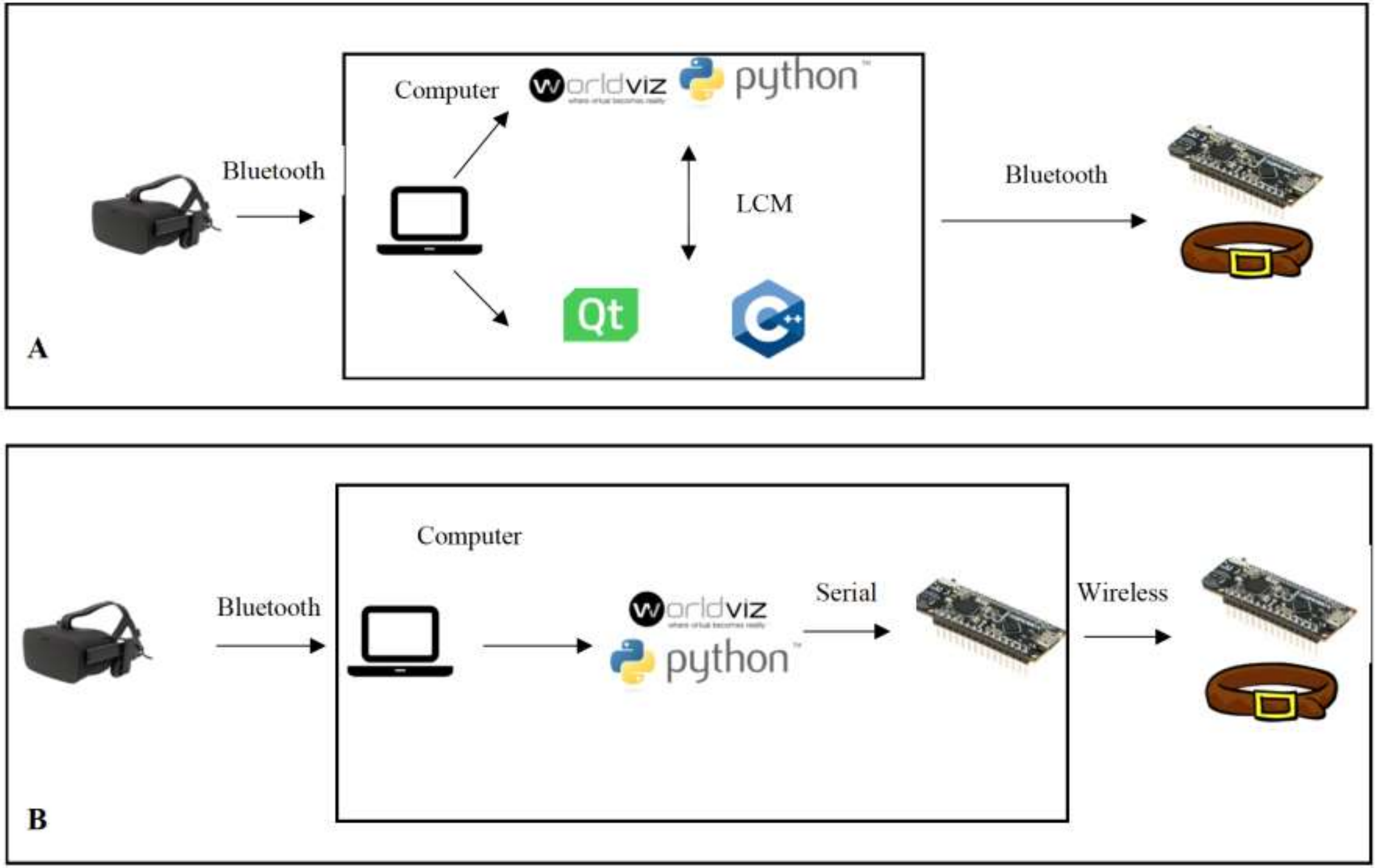
Materials


MainWindow
Timeline
0.0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5 5.0
Gesture Name
Save Gesture
Exit


Haptic Belt Designer
Save File Name:
Save Gesture
Time Span
Direction
Strength
0-0.5 sec forward weak
0.5-1.0 sec forward weak
1.0-1.5 sec forward weak
1.5-2.0 sec forward weak
2.0-2.5 sec forward weak
2.5-3.0 sec forward weak
3.0-3.5 sec forward weak
3.5-4.0 sec forward weak
4.0-4.5 sec forward weak
4.5-5.0 sec forward weak

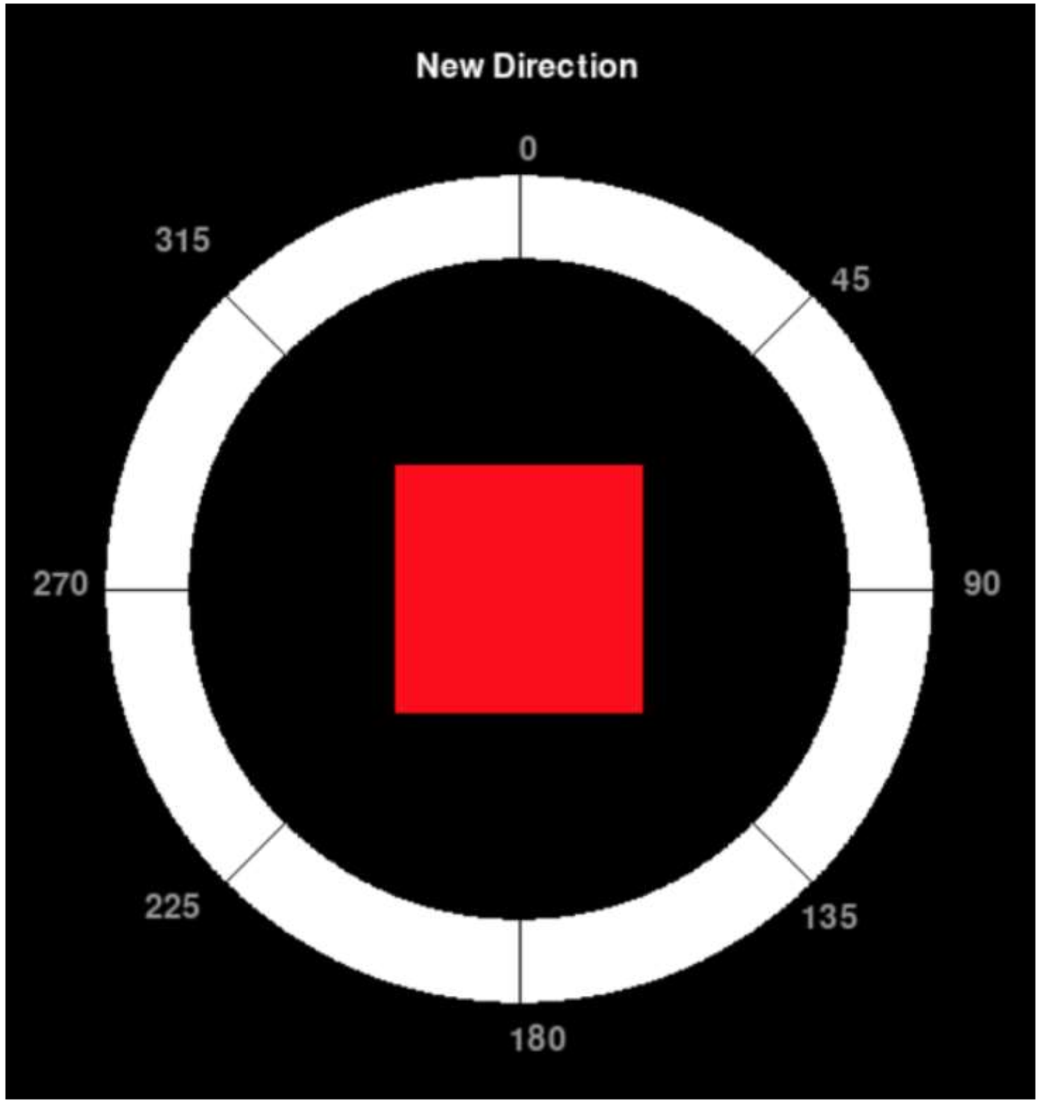

BlindFind Controller
Create Commands
Execute Commands
Load Gestures
Not Connected
Connect to Bluno
Vizard
Disconnect

Communication



Test 1: Vibratory Perception

- Examine single-motor vibration (8-motor and 12-motor belt) and Gaussian vibration scheme (12-motor belt)
- Subjects were told to click on the direction they feel best represents the direction of vibration



Test 1: Vibratory Perception

8-Motor Belt
Single-Motor Vibrations

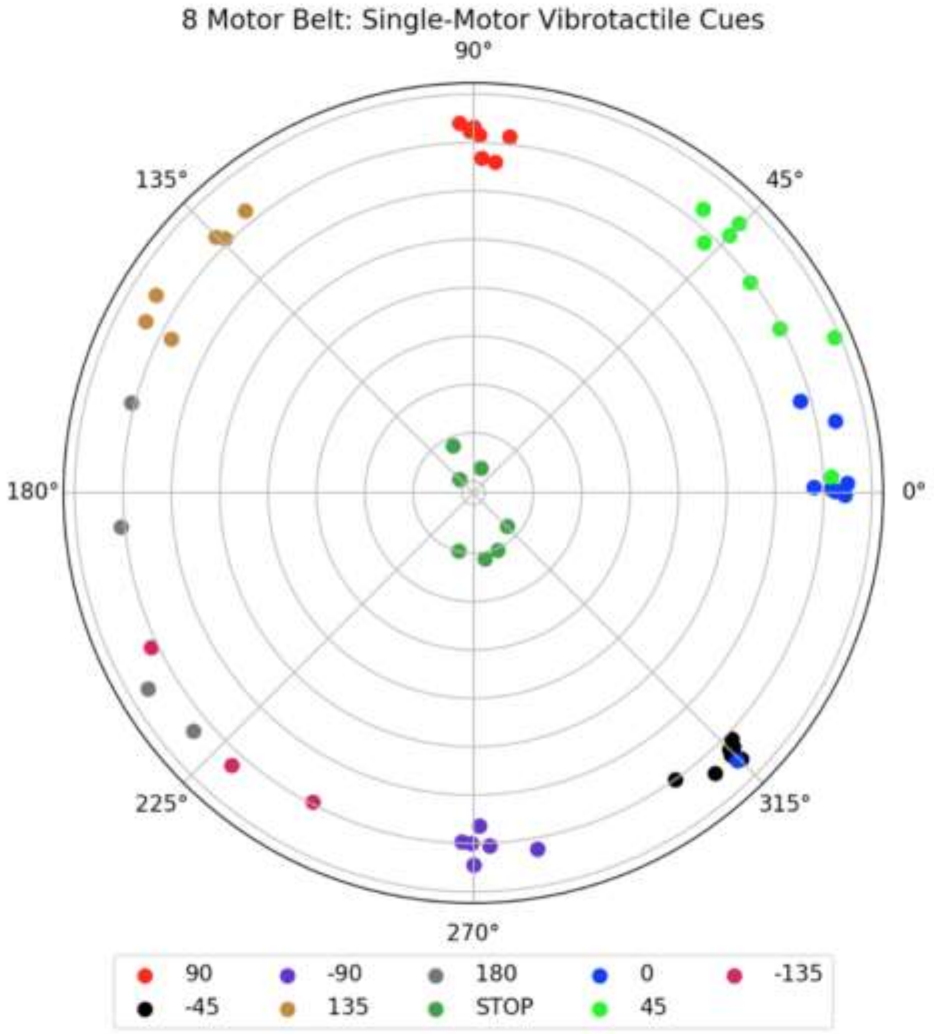


Table 3: Positional Data [8-Motor]

Direction	Mean Angle Error	Max Angle Error
0º	7.69º (7.69)	45.43 º
45º	12.21º (13.5)	42.44 º
90º	2.10º (1.88)	5.77 º
135º	9.23º (7.32)	17.98 º
180º	22.91º (13.6)	40.36 º
225º	13.44º (7.19)	19.44 º
270º	2.69º (3.47)	10.19 º
315º	2.37º (3.29)	9.77 º
ALL	8.03º (11.26)	45.43º
Cue	**Percent Accuracy**	
STOP	100%	

Test 1: Vibratory Perception

12-Motor Belt
Single-Motor Vibrations

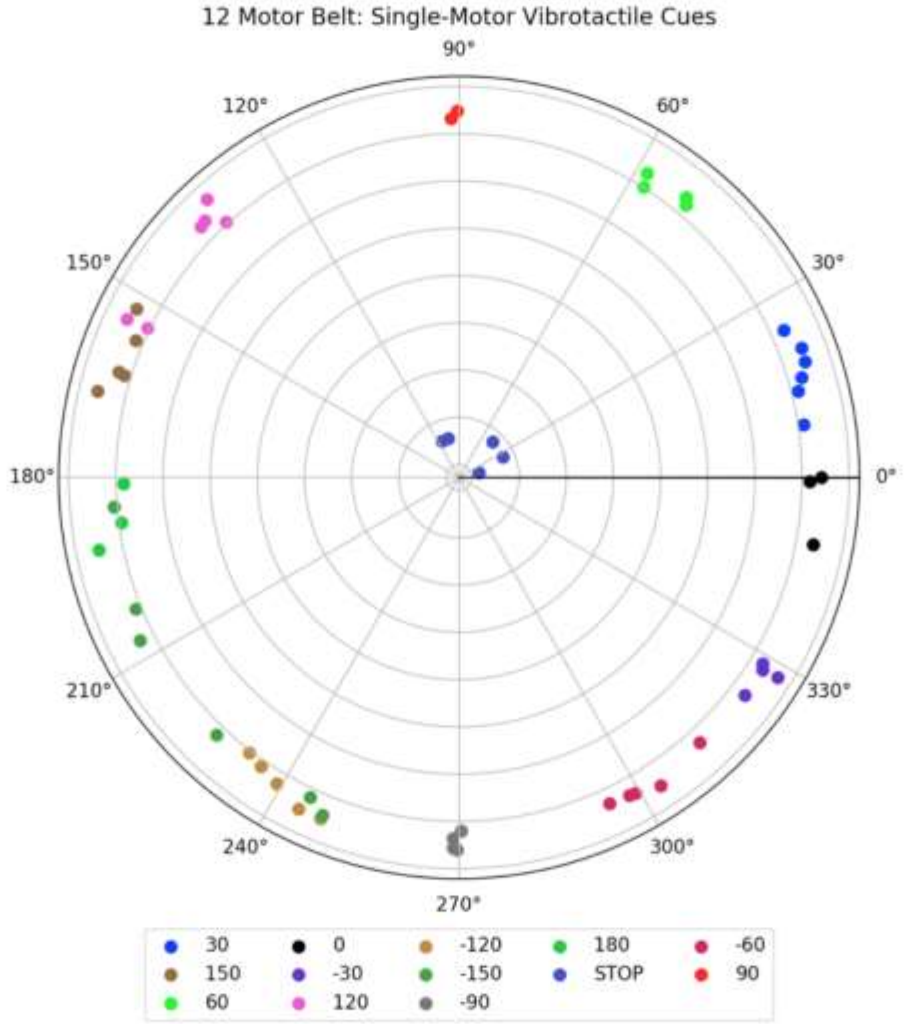


Table 4: Positional Data [12-Motor]

Direction	Mean Angle Error	Max Angle Error
0º	3.76 º (4.87)	10.64 º
30º	12.89º (4.92)	21.28 º
60º	5.78 º (3.69)	9.85 º
90º	0.78 º (0.47)	1.25 º
120º	20.72 º (9.81)	34.52 º
150º	10.39 º (5.02)	16.62 º
180º	6.66 º (4.28)	11.37 º
210º	20.91 º (12.99)	37.85 º
240 º	4.92 º (2.54)	7.80 º
270 º	0.62 º (0.31)	0.93 º
300 º	4.66 º (4.11)	12.34 º
330 º	3.27º (2.31)	7.24 º
ALL	9.41º (9.53)	37.85 º
Cue	**Percent Accuracy**	
STOP	100%	

Test 1: Vibratory Perception

12-Motor Belt
Vibrational Intensity

Table 2: Vibration Levels in the Gaussian encoding scheme

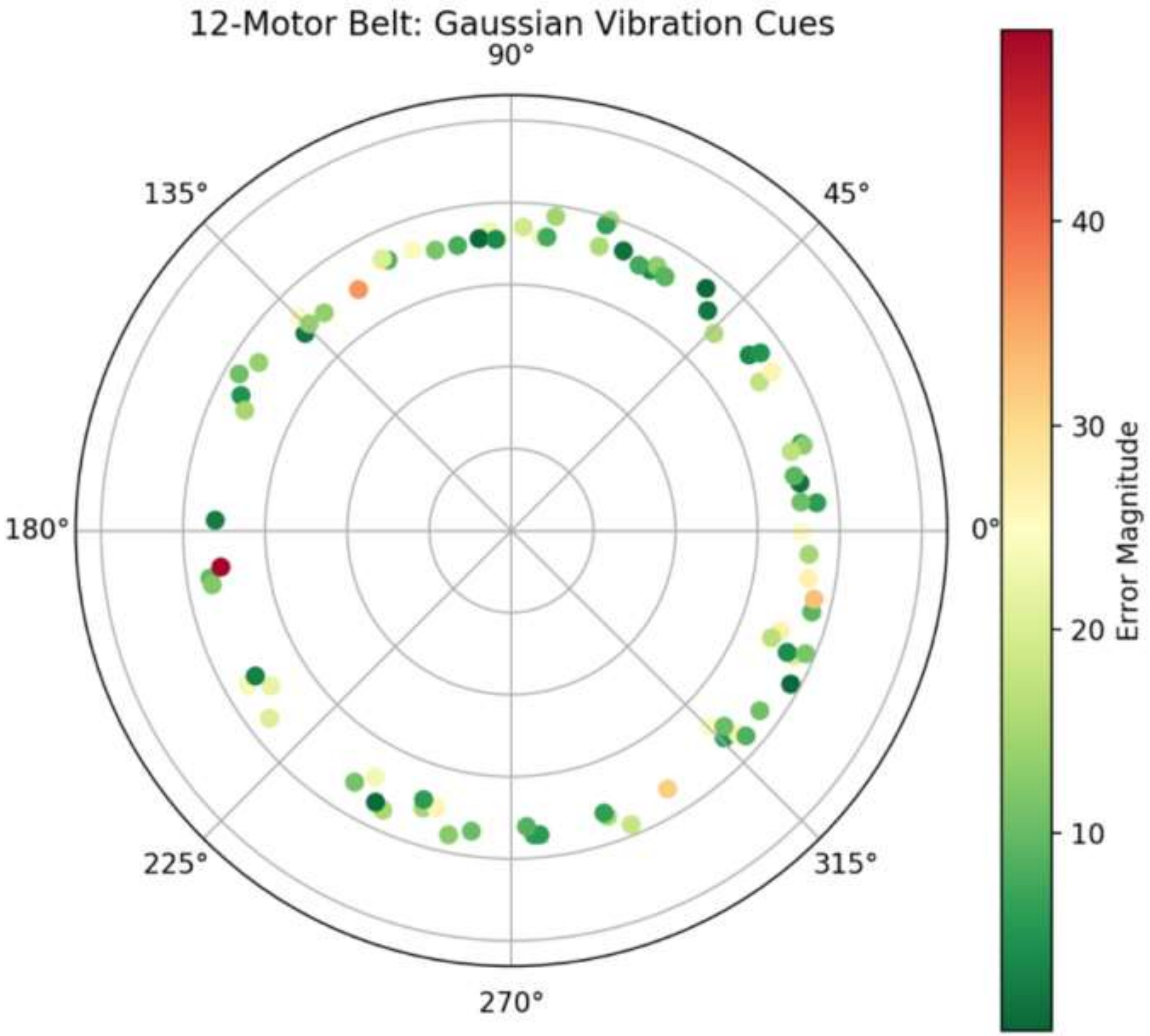
Gaussian Vibration	HIGH (milliseconds)	LOW (milliseconds)	DUTY CYCLE
1	20	0	100%
2	16	4	80%
3	12	8	60%
4	8	12	40%
5	4	16	20%

Table 6: Motor Intensity Discrimination Accuracy

		RHS Motor Intensities				
		1	2	3	4	5
LHS Motor Intensities	1		100%	100%	100%	100%
	2	100%		100%	100%	100%
	3	100%	100%		100%	100%
	4	100%	100%	83.33%		100%
	5	100%	100%	100%	50%	

Test 1: Vibratory Perception

12-Motor Belt
Gaussian Vibration Scheme



Test 1: Vibratory Perception (Summary)

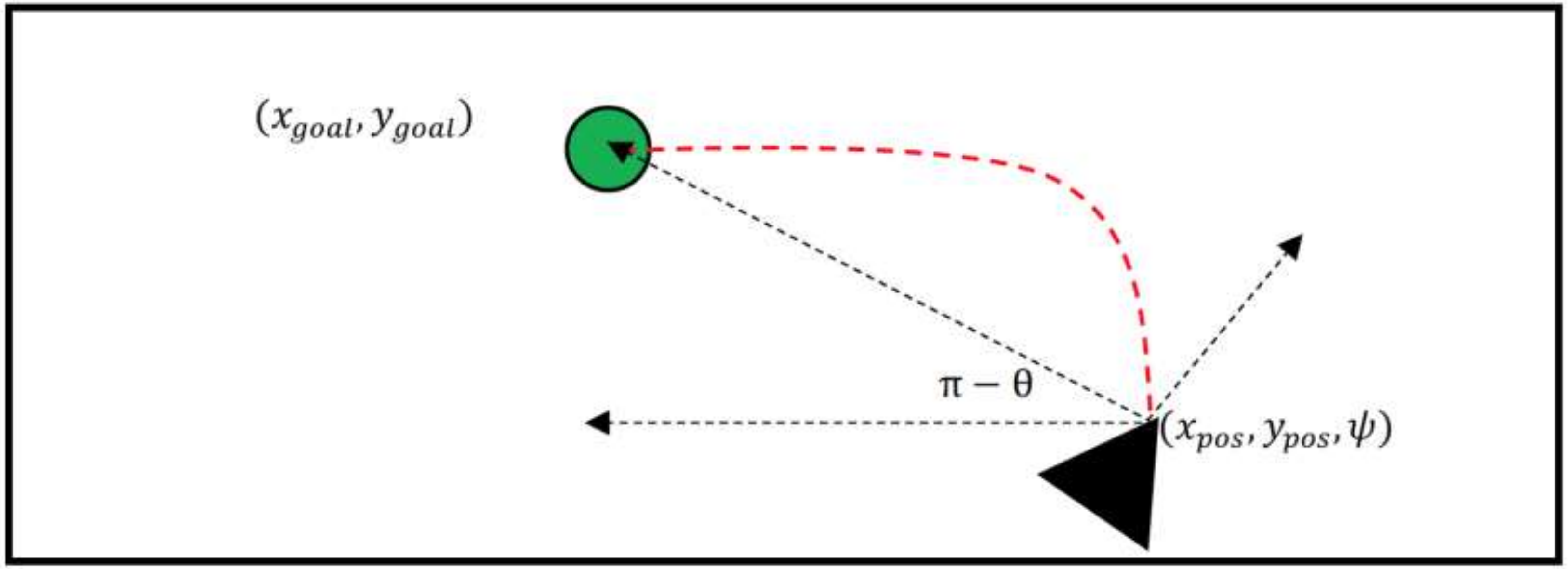
Table 7: Summary Statistics for Gaussian Vibration Trial

Error Statistic	12-Motor Gaussian (°)	12-Motor Single Vibration (°)	8-Motor Single Vibration (°)
Mean Error	13.77 (9.31)	9.41° (9.53)	8.03° (11.26)

Navigation Methods

2) Discrete Control

3) Continuous Feedback

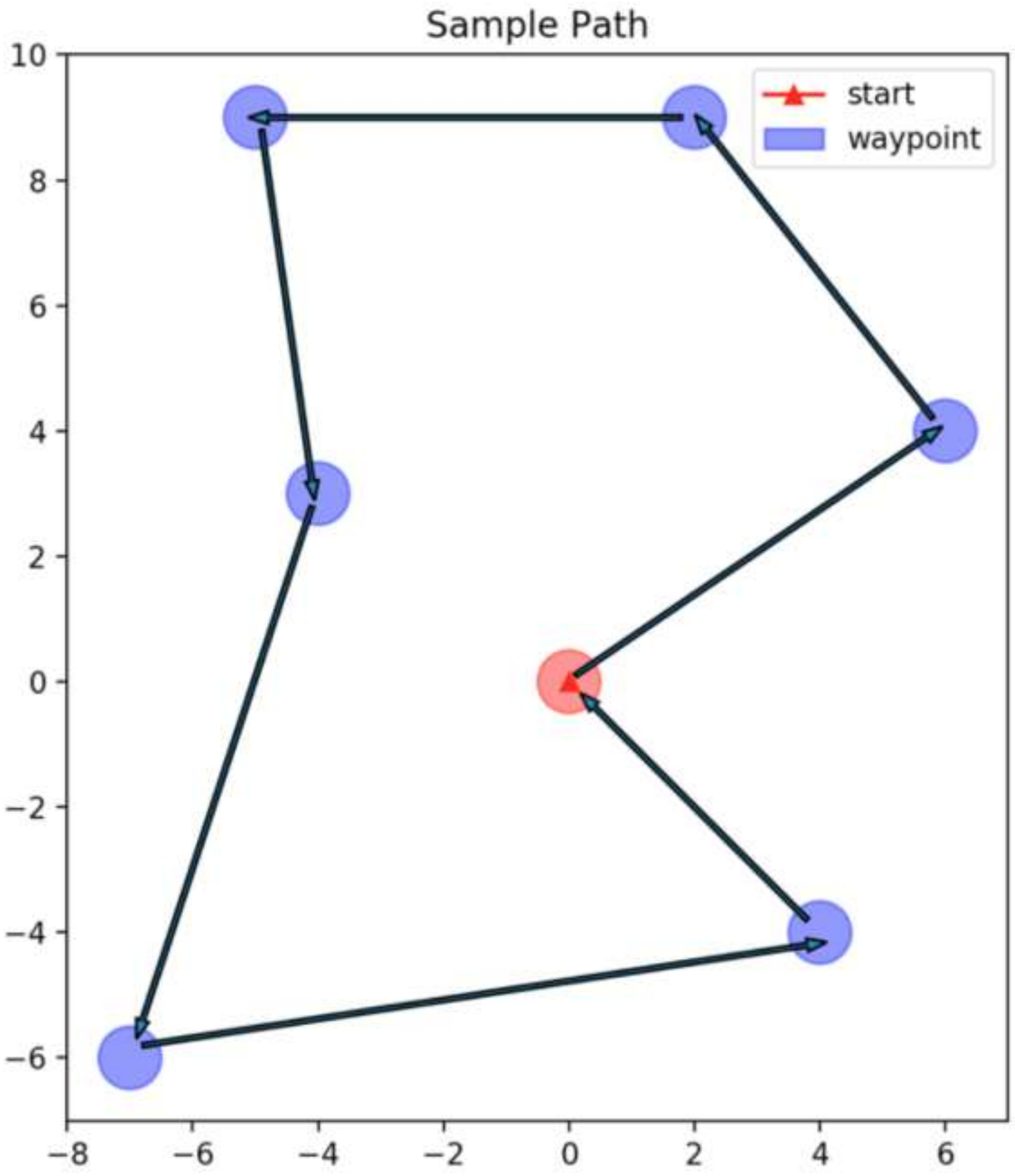


$$\begin{pmatrix} dx \\ dy \\ \theta \end{pmatrix} = \begin{pmatrix} x_{goal} - x_{pos} \\ y_{goal} - y_{pos} \\ \tan^{-1}(\frac{dx}{dy}) \end{pmatrix}$$

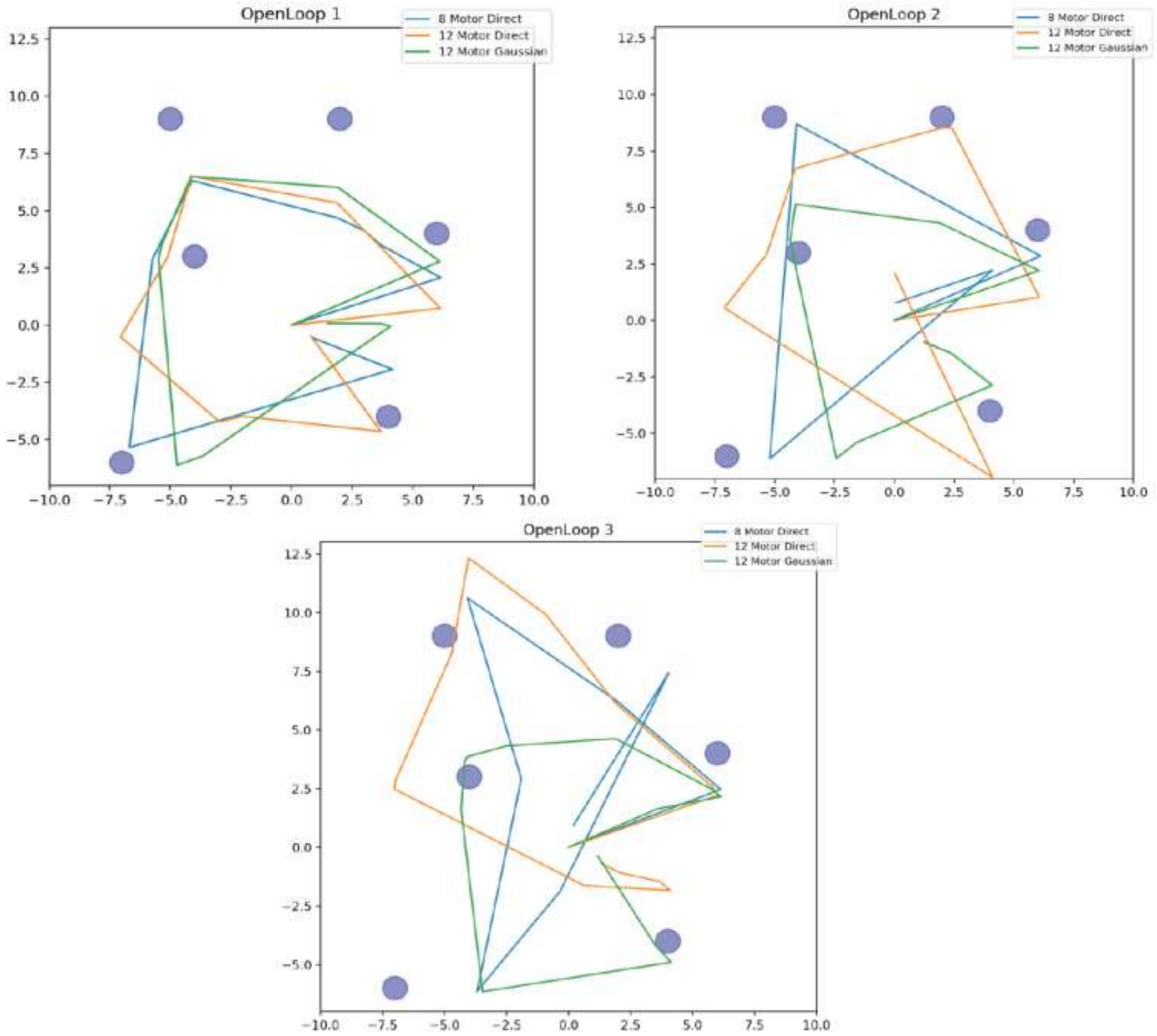
$$d\psi = \psi - \theta$$

Test 2: Discrete Control

- Navigate to 7 waypoints receiving only an initial signal from the current point
- Keyboard-based navigation in virtual reality (W-A-S-D)



Test 2: Discrete Control



Test 2: Discrete Control

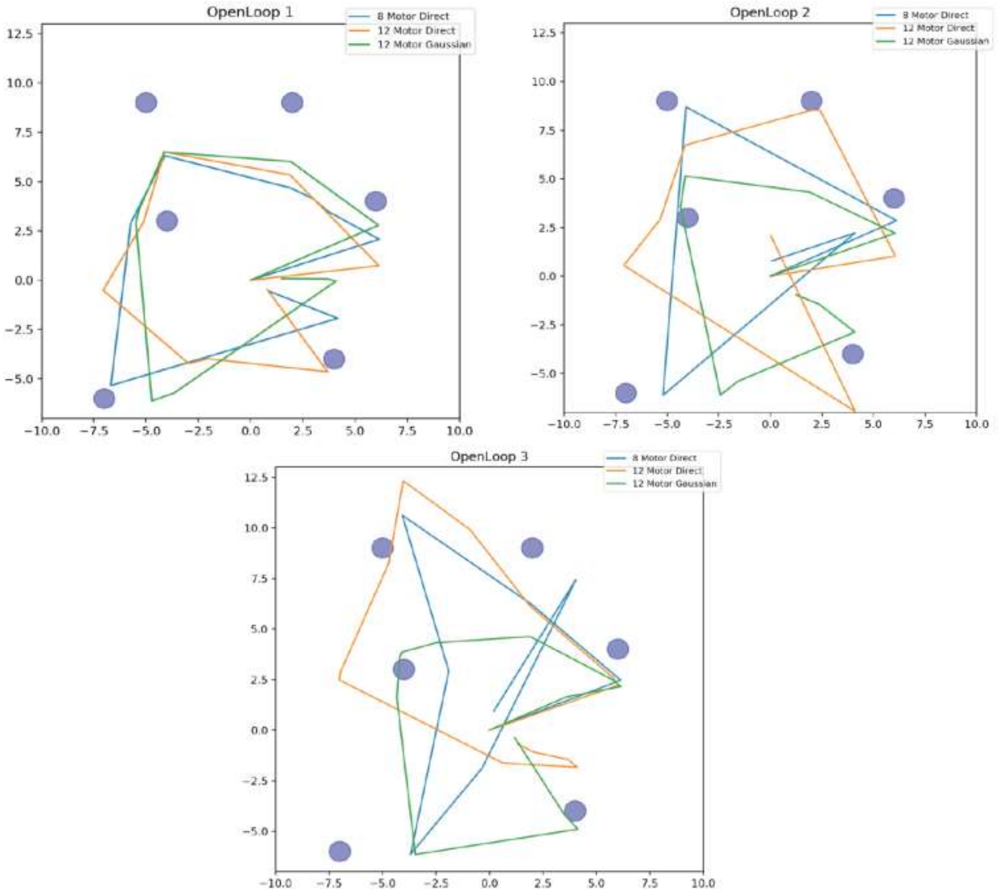
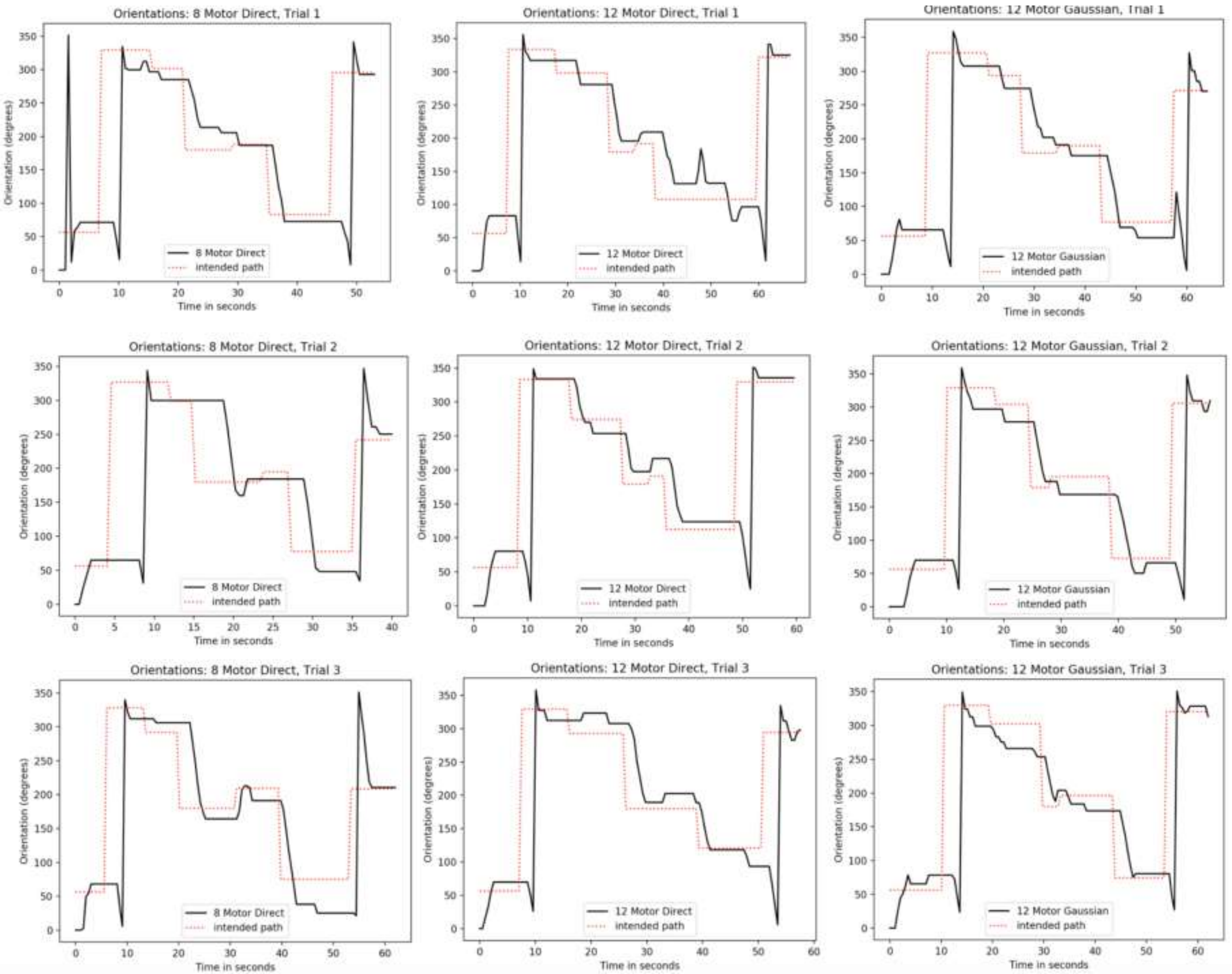


Table 8: Summary Orientation Results for Discrete Control Tests. Mean accuracy fraction is calculated as the fraction of time when the participant's orientation was within 15° of the intended accuracy.

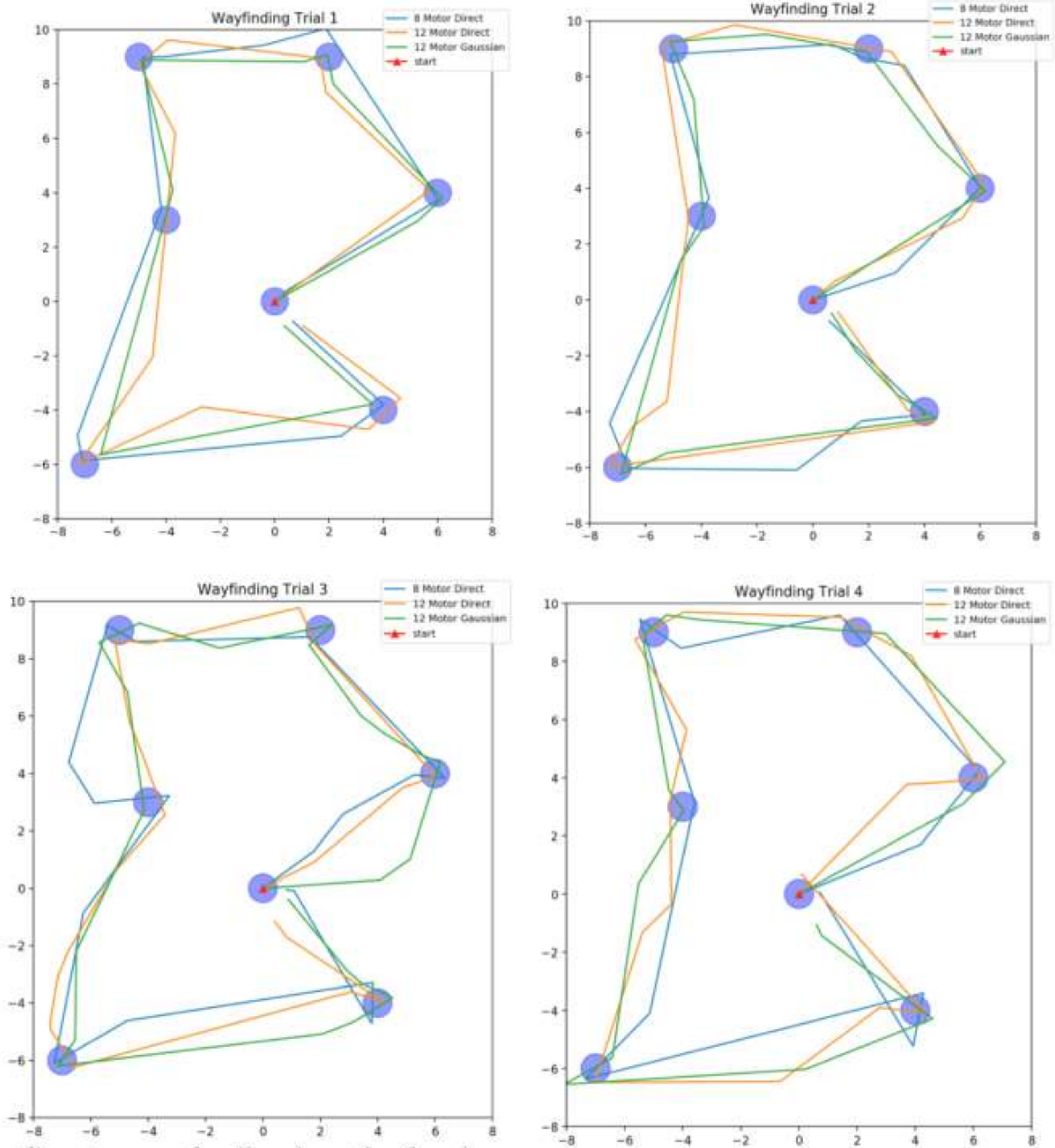
	Time (s)	Mean Deviation (°)	Mean Accuracy Fraction
8-Motor Direct	103.33	37.65 (4.95)	0.55
12-Motor Direct	122.33	28.70 (4.80)	0.57
12-Motor Gaussian	121.33	33.03 (0.69)	0.56

Test 2: Discrete Control



Test 3: Continuous Feedback

- Continuously send navigational vibrations every 0.4 seconds
- Keyboard-based navigation in virtual reality (W-A-S-D)



Test 3: Continuous Feedback

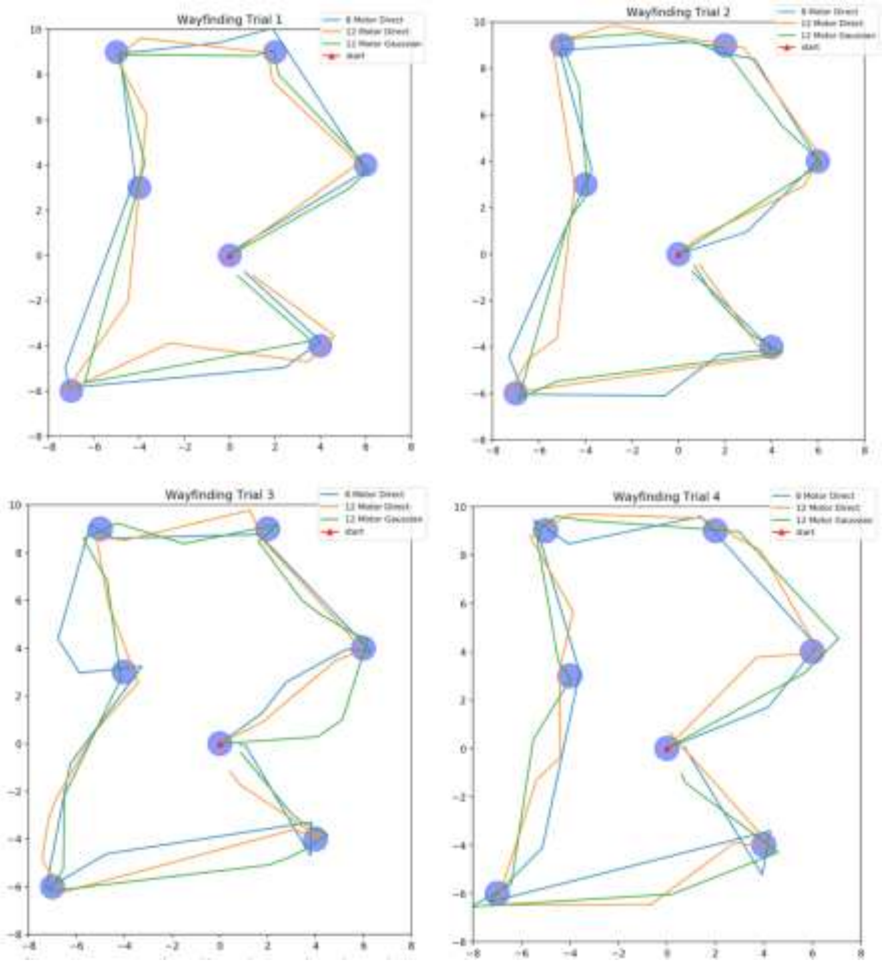
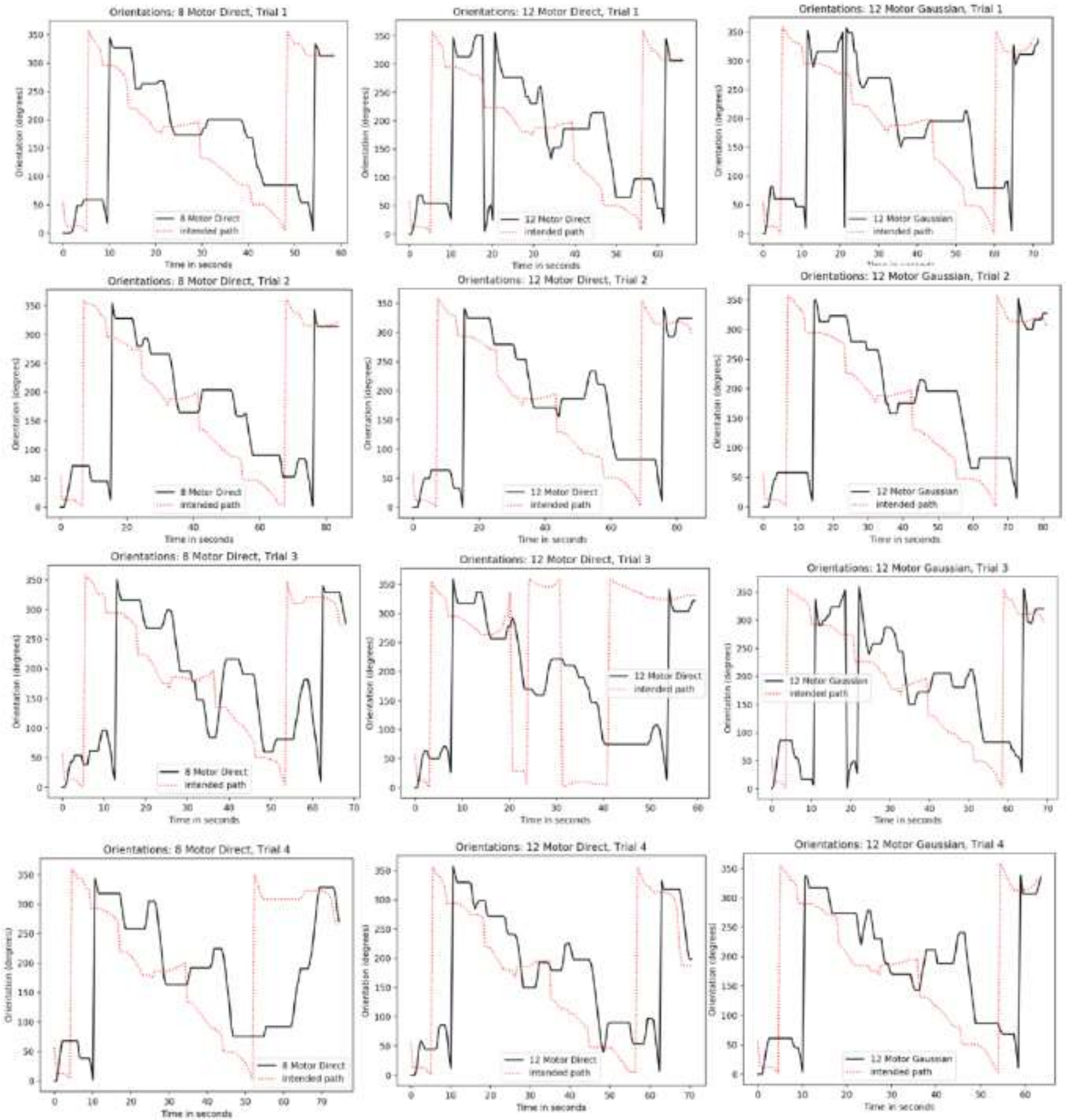


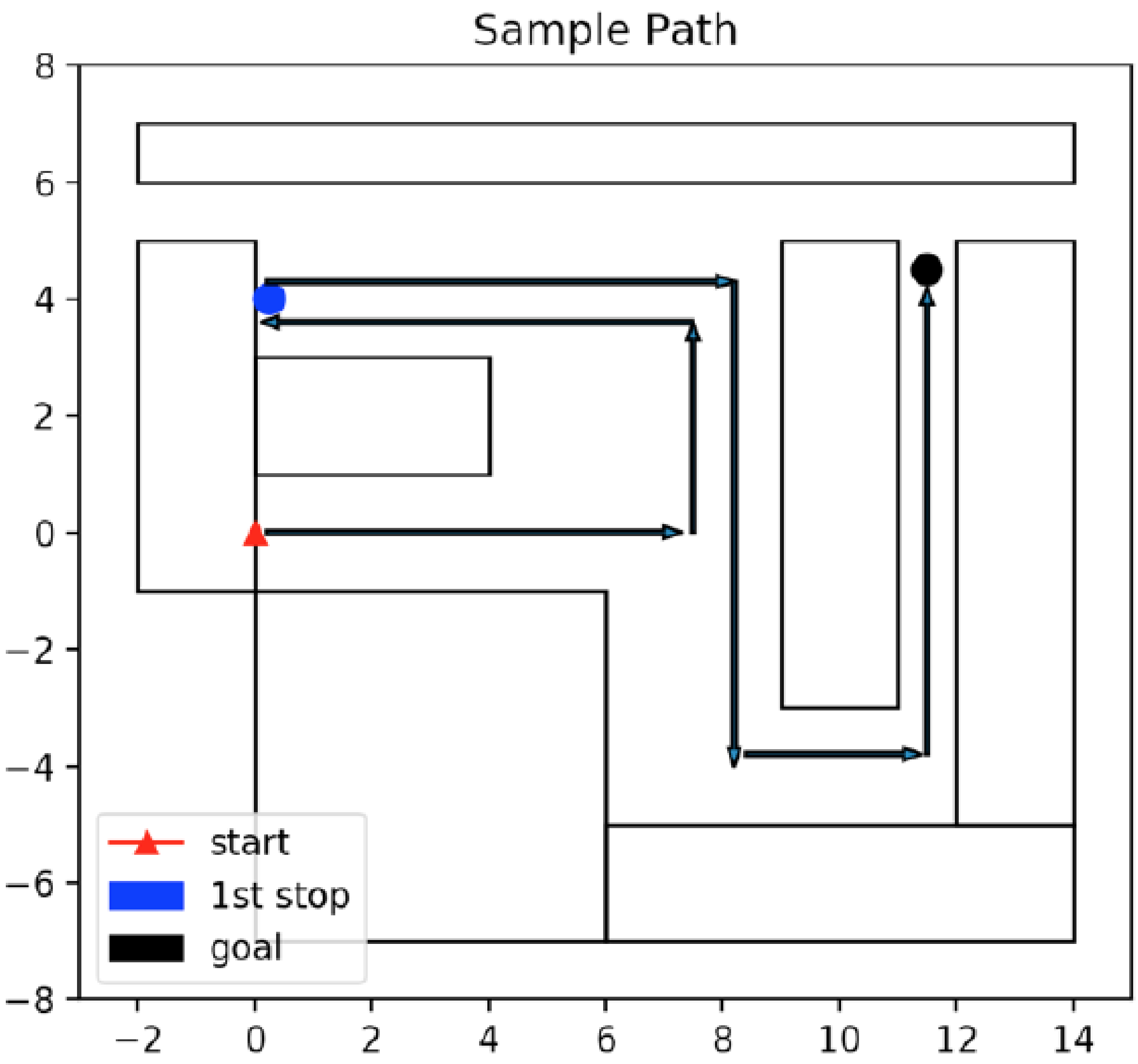
Table 9: Summarized statistics from the wayfinding task under continuous feedback.

Vibration Pattern	Mean Completion Time (sec)	Mean Distance from Path (m)
8-Motor Direct	142.25 (18.27)	0.379 (0.121)
12-Motor Direct	142.25 (18.35)	0.371 (0.071)
12-Motor Gaussian	142.5 (12.66)	0.319 (0.143)

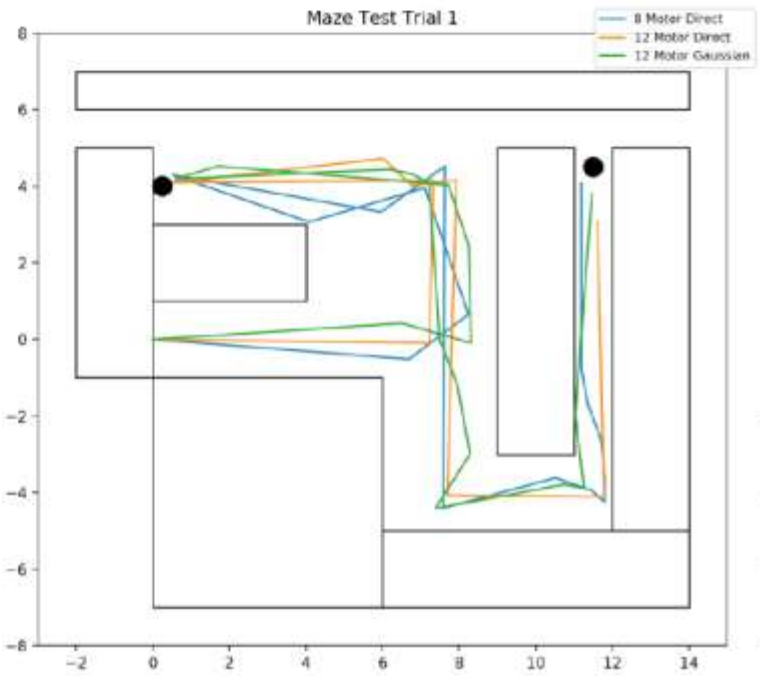
Test 3: Continuous Feedback

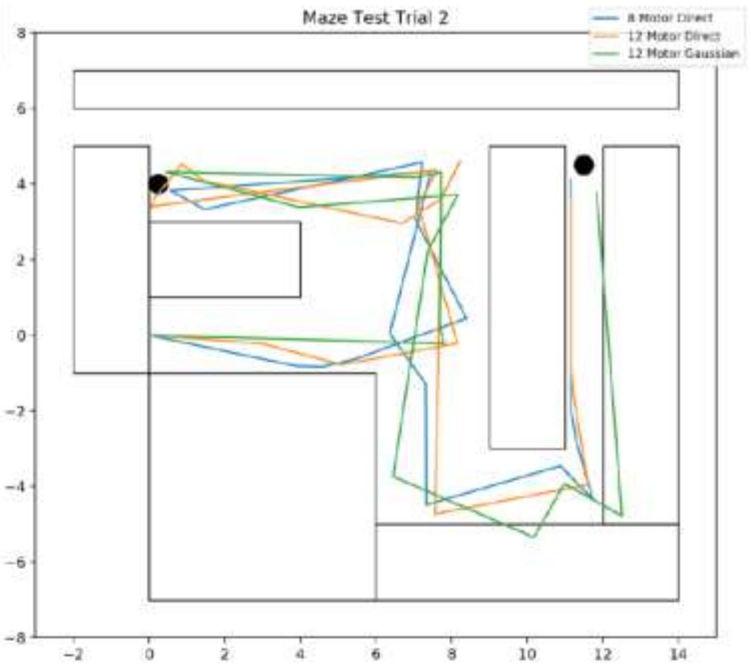


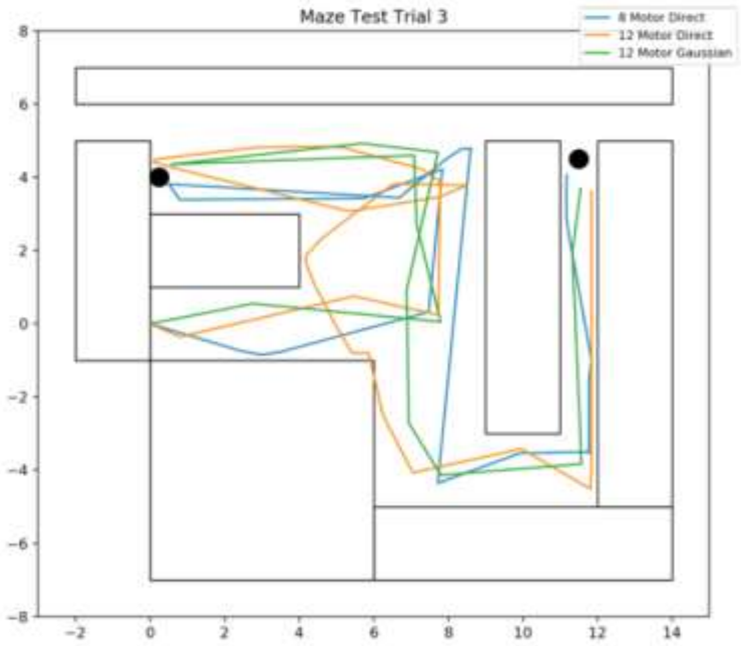
Test 3: Continuous Feedback (2^{nd} Task)



Test 3: Continuous Feedback (2nd Task)







Test 3: Continuous Feedback (2^{nd} Task)

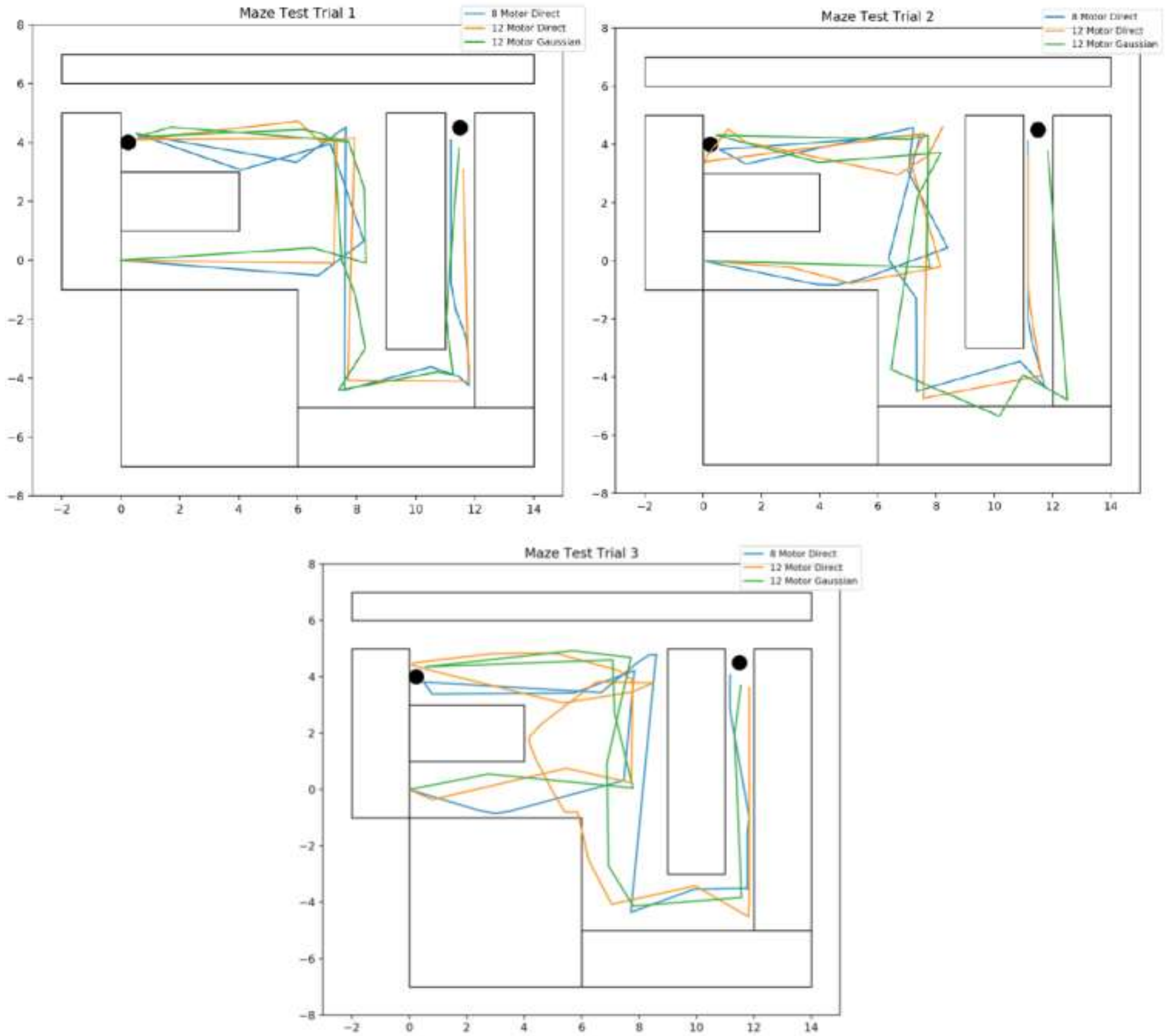


Table 10: Summarized statistics from the maze task under continuous feedback.

Vibration Pattern	Mean Completion Time (sec)	Mean Distance from Path (m)
8-Motor Direct	153.93 (37.12)	0.381 (0.08)
12-Motor Direct	120.33 (9.39)	0.400 (0.17)
12-Motor Gaussian	125.67 (14.82)	0.356 (0.132)

Conclusions

Investigate the effect of haptic belt motor density and vibration strength on vibratory perception of direction

We see a slightly higher level of perception error with higher motor density, but we have the ability to specify a wider range of directions.

Examine the efficiency of single-motor vs. vibrating a distribution of motors at varying intensities

The Gaussian vibration scheme appears to be comparable to the single-motor vibration scheme. Its performance led to a slightly lower distance error in the wayfinding task.

How are vibratory perceptions translated into directions and navigation?

Vibratory perceptions can be translated into navigable directions. However, factors such as turning lag and persistent errors must be corrected.

Future Steps

- Rotate the belt to different orientations to further test perception results
- Effects of turning lag
- Correction for persistent errors:
  - High waypoint density
  - 2 separate navigational schemes
    - Incremental Turning Control
    - Unguided Turning Control
- 16-motor belt

Acknowledgements

- Viktor Ladics
- Hongyi Fan
- Dr. Brian Free
- Professor Benjamin Kimia
- LEMS and VEN lab

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