Redirected Walking

Reading: 15 Years of Research on Redirected Walking in Immersive Virtual Environments

Slides adapted from Evan Suma Rosenberg’s material
Every controller position is still being tracked.

Orange volume is our Primary hard bounds.
The Locomotion Problem

PHYSICAL SPACE

VIRTUAL ENVIRONMENT
Redirected Walking

Rotation Gain

VIRTUAL SPACE

PHYSICAL SPACE
Translation Gain

PHYSICAL SPACE

VIRTUAL SPACE
Curvature Gain

VIRTUAL SPACE

PHYSICAL SPACE
Why does redirection work?

Vision tends to dominate over vestibular sensation.
Measuring Detection Thresholds

- Two alternative forced choice task (2AFC)
- User repeatedly presented with a stimulus of varying level and asked to detect it
- Compute pooled probability of response (forced choice, no neutral option)
- Fit a psychometric function (sigmoid)
- Point of subjective equality (PSE) at 50%
- Detection thresholds at 25% and 75%

Detection Thresholds for Redirected Walking

Rotation Gains
49% amplification
20% dampening

Curvature Gains
arc radius >= 20 meters

Translation Gains
26% upscale
14% downscale

Discovering Near-Field VR: Stop Motion with a Touch of Light-Fields and a Dash of Redirection, 2015 SIGGRAPH AR/VR Contest Winner
Reorientation Events (Resets)
Reorientation Events (Resets)
Spatial Orientation Experiment

Virtual Target (original)
Angular Pointing Error

Rotation, Virtual Target
Real Target (original)
How does redirection influence the user’s *real world* orientation?

Can we maintain both spatial *reference frames* at the same time?
Angular Pointing Error

Rotation, Real Target
Research Questions

• How much redirection can we apply before it becomes perceptible?
  • Answer: quite a bit!

• How much redirection can we apply before it becomes noticeable?
  • Answer: even more!

• How does redirection impact the user experience?
  • spatial cognition
  • user behavior
  • task performance

• Optimal steering direction that minimizes # of resets?
Redirected Walking Systems

spatial input
- physical space dimensions
- virtual environment
- user real pose
- real to virtual origin transform
- detection thresholds

user input
- reorientation task preferences

redirection strategy
- redirection heuristic
- reorientation heuristic
- gain-smoothing mechanism
- user and system state history

Arrows indicate the flow of data from input to redirection strategy:
- translation gain
- rotation gain
- curvature gain
How much can we predict the user?

Freedom

- Linear Route
- Branching Pathways
- Open World
- Static Planning
- Dynamic Planning
- Reactive Algorithms
How much can we predict the user?

- Linear Route
- Branching Pathways
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- Reactive Algorithms
Reactive Algorithms

Steer to Center (S2C)

Steer to Orbit (S2O)
Push / Pull Reactive (P2R) Algorithm

Physical Environment

Artificial Potential Function

Gradient Field

P2R Results: Non-Convex Boundaries
P2R Results: Interior Obstacles

[Diagram showing box plots comparing resets for different environment sizes (10m and 20m) for S2C and P2R]
How much can we predict the user?

Freedom

Linear Route  Branching Pathways  Open World

Static Planning  Dynamic Planning  Reactive Algorithms
user prediction
Prediction Graph

Predictive Algorithms

FORCE [1]

MPCRed [2]

Reactive Algorithms

S2C

P2R

Performance

Deployment Overhead

prediction graph
Prediction Graph Generation

How much can we predict the user?

- Linear Route
- Branching Pathways
- Open World
- Static Planning
- Dynamic Planning
- Reactive Algorithms
Combinatorial Optimization

90 degree left turn + walk

no gain case
Alignment-based Redirection

Similarity of physical and virtual environments!
Alignment-based Redirection

How to measure similarity?

\[
\text{similarity} = |v_1 - p_1| + |v_2 - p_2| + |v_3 - p_3|
\]


Alignment-based Redirection

How to measure similarity?


Alignment-based Redirection

How good is it?

Alignment

Potential Fields

S2C

Number of resets: 0

Number of resets: 0

Number of resets: 0
Alignment-based Redirection

How good is it?

Environment A  Environment B  Environment C

Physical

Virtual
Alignment-based Redirection

How good is it?
Alignment-based Redirection

Environment A
Number of resets

Environment B
Number of resets

Environment C
Number of resets

Steering Algorithms:
- APF
- ARC
- S2C

Graphs show the number of resets for different steering algorithms across environments. The box plots compare the performance of APF, ARC, and S2C. The asterisks indicate statistical significance.
Alignment-based Redirection

Environment A

Environment B

Environment C

Steering rate (°/s)

Count

ARC  S2C  APF
Motion planning for Redirected Walking

- VR locomotion is a path planning problem!
- Robotics community is very good at path planning

Open Motion Planning Library: ompl.kavrakilab.org
Motion planning for Redirected Walking

- Configuration describes the agent’s state in an environment.

- $C_{obs} = \text{configurations that yield a collision}$
- $C_{free} = \text{configurations that don't yield a collision}$
Motion planning for Redirected Walking

Physical Environment

Virtual Environment
Motion planning for Redirected Walking

• Perform some reasoning about the environment structure
• Use insights to plan a path more intelligently
• Local similarity is important, so only do reasoning about the local surroundings!
  • Visibility polygon
Motion planning for Redirected Walking
Motion planning for Redirected Walking

$C_{free}$
Motion planning for Redirected Walking

Physical Environment

Virtual Environment

Superimposed C free
Motion planning for Redirected Walking

Physical Environment

Virtual Environment

Superimposed
Motion planning for Redirected Walking

Physical Environment

Virtual Environment

Superimposed $C_{\text{free}}$
Motion planning for Redirected Walking

Physical Environment

Virtual Environment
Motion planning for Redirected Walking

Physical Environment

Virtual Environment
Distractors for Redirected Walking

- Want to mask the injected rotations & translations
  - Give users something else to focus on
  - Force user to rotate their head

Distractors for Redirected Walking

• Distractor should feel realistic and compelling enough to grab the user’s attention

https://www.youtube.com/watch?v=Z2ROu_FpJuU

https://youtu.be/96rxBzMK-2w?t=203
Distractors for Redirected Walking

• How to determine the distractor’s behavior/movement?
  • Also motion planning!
  • Consider user’s current position in the environments, and the current context
Haptics + Redirected Walking

• Can use haptics to improve the realism and strength of distractors

• Passive haptics is the opposite of redirected walking
  • Can we combine them? Sometimes…


Multi-User Redirection
Deep Learning for Redirected Walking


https://www.youtube.com/watch?v=ZZfZ2AC2ec0