Smooth Nearness Diagram Navigation

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Motivation & Approach

- Motivation
  - Smooth navigation through cluttered, potentially dynamic environments

- Approach
  - Built on Nearness Diagram+ method
  - “Gap”-based

- J. Minguez, J. Osuna, and L. Montano, “A 'divide and conquer' strategy based on situations to achieve reactive collision avoidance in troublesome scenarios,” ICRA, 2004
Motion Control Framework

- SND Navigation
  - Local, reactive planner
  - Inputs:
    - Rangefinder data
    - Goal direction
  - Outputs
    - Safe direction
    - Linear speed
Brief Comparison

• ND+
  - Gap and valley based
  - 6 motion laws
  - Avoidance to closest left and right obstacle point

• SND
  - Gap and valley based
  - 1 motion law
  - Weighted avoidance of all obstacle points
Gaps and Regions

- **Gap**: Discontinuity in measured distance or obstacle next to max range measurement
  - Also classified as right or left
- **Region**: Between two consecutive gaps

Rising Gaps

- Rising gap: Right gap on right side of region, left gap on left side of region
  - Region dependent
  - Indicate a potential path into area robot cannot currently see
Valley: A region with at least one rising gap
  - If region has two rising gaps, closest to $\theta_{\text{goal}}$ is used
  - Only consider valleys wide enough for robot

Best valley ($V_{\text{best}}$): Valley closest to $\theta_{\text{goal}}$
Headings from Best Valley

- Safe rising gap, $\theta_{srg}$
  - Deflected around obstacle creating gap

$$\theta_{srg} = \theta_{rg} \pm \sin\left(\frac{R + D_s}{D_{rg}}\right)$$

- Valley bisector, $\theta_{mid}$

$$\theta_{mid} = \theta_{rg} \pm \frac{\text{dist}(\theta_{rg}, \theta_{og})}{2}$$

$R = \text{robot radius}$
$D_s = \text{safety buffer around robot}$
$D_{rg} = \text{distance to obstacle at rising gap}$
ND+ Method

- “Divide and conquer” strategy
  - 4 binary conditions defining 6 situations
- Robot behavior defined for each situation
- Smooth transitions between some pairs of behaviors

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SND Desired Heading

Three choices for desired heading, $\theta_{des}$:

$$\theta_{des} = \begin{cases} 
\theta_{goal} & \text{if } \theta_{goal} \in V_{best} \\
\theta_{srg} & \text{elif } \text{dist}(\theta_{srg}, \theta_{rg}) < \text{dist}(\theta_{mid}, \theta_{rg}) \\
\theta_{mid} & \text{else}
\end{cases}$$
SND Obstacle Avoidance

- For each obstacle point
  - Threat measure:
    \[ t_i = \text{sat}_{[0,1]} \left( \frac{D_s + R - D_i}{D_s} \right) \]
  - Deflection angle:
    \[ \delta_i = t_i \cdot \text{dist} \left( \theta_i + \pi, \theta_{des} \right) \in [-\pi, \pi] \]
  - If robot is touching \( i^{\text{th}} \) obstacle, \( \theta_{des} + \delta_i \) points directly away from obstacle
SND Obstacle Avoidance II

- Net threat measure:
  \[ T_{total} = \sum_{i=1}^{N} t_i^2 \]

- Net deflection angle:
  \[ \Delta_{avoid} = \sum_{i=1}^{N} \frac{t_i^2}{T_{total}} \delta_i \]

- Final trajectory:
  \[ \theta_{traj} = \theta_{des} + \Delta_{avoid} \]
  \[ v_{limit} = \left( 1 - \text{max} \left( t_i \ldots t_N \right) \right) \cdot v_{max} \]
Smoothness Conjecture

• For a rangefinder with infinitesimal resolution:

\[ T_{\text{total}}(x, y) = \oint t(\alpha, x, y)^2 \, d\alpha \]

• Reminiscent of formula for area of visibility space:

\[ A_{\text{visible}}(x, y) = \oint r(\alpha, x, y)^2 \, d\alpha \]

• Visibility area is Locally Lipschitz continuous in non-convex polygonal environment with holes

Testing Setup

- Player/Stage Robotics Software
  - Open-source tools for robotics
  - Easy portability from simulation to hardware
  - Implemented both ND+ and SND
  - Version 2.0.3
- Videre Designs “Erratic” mobile robot platform
- Hokuyo URG laser rangefinder
Simulations
Simulation Trajectories

SND

ND+

Smooth Nearness Diagram Navigation
Experiments

SND

ND+

Smooth Nearestness Diagram Navigation
Summary

• Smooth Nearness Diagram Navigation
  – Adapted from ND+ method
  – Based on gaps
  – Single motion law for all situations
  – Improved smoothness in angular heading
  – Single parameter: size of safety buffer

• Future directions
  – Explore proofs of smoothness
  – When is SND guaranteed to find a safe path?
Thank you

Questions?