Towards a safe, low-cost, intelligent wheelchair

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Overall goal

- To build an Intelligent Wheelchair that acts as a mobility assistant for its human passenger
  - Help people with perception and mobility disabilities

- The wheelchair should be able to autonomously execute commands issued by its passenger
  - Should learn the spatial structure of its environment
  - Should “communicate” with its passenger

- The wheelchair should also ensure the safety of its passenger and be low cost
Contribution: Integration of technologies

- Integration of three technologies necessary for realizing the intelligent wheelchair
  - Local metrical mapping
    - Vision based to ensure detection of all hazards and reduce cost
  - Local topology extraction
    - Symbolic structure extraction to facilitate human-robot interaction
  - Local motion planning
    - Plan trajectories to ensure the passenger’s comfort & safety

These technologies are relevant for other autonomous vehicles, specially those with humans in the loop
The intelligent wheelchair

- Multiple sensors
  - Stereo camera
  - Optical encoders
  - Lasers

- Computational backpack interfaces with hardware

- Laptop runs code-base
  - Uses the HSSH cognitive architecture
Integration

Robot
- Stereo Camera
- Lasers
- Encoders
- Motors

Local Metrical Mapping
- Safety Map
- Pose

Localization
- Laser Scan
- Odometry
- Pose

Control
- Velocity command

User Interface
- User

Local Topology Extraction
- Safety Map
- Pose

Topology + Gateways

Local Motion Planning
- Trajectory
Vision-based local metrical mapping

- Use stereo cameras to build the local metrical map
  - Cameras are low-cost compared to lasers
  - Cameras see in 3D and detect hazards that 2D lasers cannot

- The vision-based mapping algorithm [Murarka & Kuipers, IROS-09]
  - Detects inclines, drop-off edges, overhangs, & obstacles
  - Works in real-time
  - Has been quantitatively shown to rarely mark unsafe places as safe
Vision-based mapping: Algorithm outline

- Compute depth map from stereo images
- Build a 3D model
- Segment and fit planes to 3D Model
- Analyze planes to get a local safety map

Legend:
- Level
- Inclined
- Non-ground
- Drop-off Edge
- Unknown
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Topology + Gateways

Stereo Image

Trajectory
Local topology: A symbolic model

- *Local topology* can be efficiently created from the local safety map

- The local topology symbolically describes the local surround
  - Detect places vs. paths
  - Describe places using circular ordering of local paths
  - Uses a concept called *gateways*.

- *Gateways* can be thought of as exits or entrances
  - Can provide goal poses to local motion planning

- Provides human user with a small number of high-level actions
  - e.g., turn left, go forward
  - Currently a simple GUI is used to *Travel* between and *Turn* at intersections.
Local topology extraction: Algorithm outline

- Find gateways
- Align the gateways to find paths
- The local topology is the circular ordering of paths
- The ordering provides natural descriptions of left, right, forward, etc.

\[
\begin{align*}
(\langle \tilde{\pi}_a^+, 1 \rangle & \leftrightarrow \langle g_4, \text{in} \rangle, \langle g_1, \text{out} \rangle) \\
(\langle \tilde{\pi}_b^+, 1 \rangle & \leftrightarrow \langle g_2, \text{out} \rangle) \\
(\langle \tilde{\pi}_c^-, 0 \rangle & \leftrightarrow \langle g_5, \text{in} \rangle) \\
(\langle \tilde{\pi}_d^+, 1 \rangle & \leftrightarrow \langle g_3, \text{out} \rangle) \\
(\langle \tilde{\pi}_a^-, 1 \rangle & \leftrightarrow \langle g_1, \text{in} \rangle, \langle g_4, \text{out} \rangle) \\
(\langle \tilde{\pi}_d^-, 0 \rangle & \leftrightarrow \langle g_3, \text{in} \rangle) \\
(\langle \tilde{\pi}_c^+, 1 \rangle & \leftrightarrow \langle g_5, \text{out} \rangle) \\
(\langle \tilde{\pi}_b^-, 0 \rangle & \leftrightarrow \langle g_2, \text{in} \rangle)
\end{align*}
\]
Integration

User Interface

User

Local Metrical Mapping

Safety Map

Stereo Image

Local Topology Extraction

Topology + Gateways

Pose

Local Motion Planning

Trajectory

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Odometry

Velocity commands

Trajectory
The motion of a wheelchair should not only be safe, it should be comfortable.

The framework for comfortable motion [Gulati et al., IROS-09]

- Characterizes discomfort as a performance measure
- Finds a trajectory that locally minimizes discomfort
  - A trajectory encodes a geometric path and motion on the path in time
- Works in real-time for a variety of motion tasks
- Is customizable according to user preferences
Safe and comfortable local motion planning: Algorithm outline

- Plan obstacle free path using RRT.

- Create an initial guess of trajectory using
  - the waypoints from RRT,
  - the boundary conditions on pose, velocity and acceleration.

- Use variational optimization to find a trajectory that
  - minimizes a cost functional in the neighborhood of the initial guess,
  - satisfies boundary conditions.

- The cost functional balances travel time and smoothness of motion.
  \[
  J = t_f + \int_0^{t_f} (w_1 f_1 + w_2 f_2 + \ldots) dt
  \]

\( f_1 \) and \( f_2 \) are functions of pose and its derivatives.
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Topology + Gateways

Stereo Image
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Pose

Local Topology Extraction

Topography + Gateways
Experiments: Successes
Vision map + Local topology

- Local topology extracted using a vision map differs from that obtained using a laser map
- Happens because vision sees additional objects
  - Narrow FOV is another cause

Four-way corridor intersection with stairs

Laser map

Laser based local topology identifies a place

Vision-based local topology is different
Vision map + Local topology

When the robot investigates the region further it identifies the drop-off at the stairs

The vision-based local topology is updated and the gateway at the top of the stairs is removed
Vision map + Comfortable motion

- The vision-based maps successfully support motion planning
  - Algorithm is unchanged from that used with lasers

- Additionally, vision maps allow the robot to avoid hazards not seen by the horizontal laser

Environment with an overhanging bench

RRT plan

Trajectory successfully followed by the robot
Vision map + Local topology + Comfortable motion example: Sidewalk navigation

Navigating a sidewalk
Local topology correctly identifies the sidewalk as a path
Planned trajectory

Map built using the horizontal lasers. The drop-off at the sidewalk curb is not identified. Such a map is unsafe to use.
Experiments: Failures
Poor texture

- Regions with poor texture get marked as unknown
  - The robot is still safe as unknown areas are not traversed

- The extracted local topology can be incorrect in some circumstances

A path is incorrectly identified as a “T” junction
Summary of experimental results

- Vision maps model additional regions in the world compared to laser maps. As a result:
  - local topologies differ between vision and laser maps
  - motion planning is safer as more hazards are seen

- Low texture and low light areas cause some regions to appear as unknown in vision maps
  - This leads to the extraction of incorrect local topologies
Conclusions

- Demonstrated the integration of three technologies necessary for an intelligent wheelchair
  - **Vision-based local metrical mapping**: For detecting hazards
  - **Local topology extraction**: For natural human-robot interaction
  - **Safe and comfortable motion planning**: For human-acceptable motion

- The three technologies demonstrated should be useful for a variety of intelligent vehicles
Future work

- Handling low texture and poor lighting when building maps and extracting topologies
- Guaranteeing hazard avoidance in trajectory planning
Thank You!

Questions?