Group Surfing: A Pedestrian-Based Approach to Sidewalk Robot Navigation

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INTRODUCTION

We propose a navigation system for mobile robots in pedestrian-rich sidewalk environments. We developed a group surfing method which imitates pedestrian behaviour to support sidewalk navigation in a safe and socially-compliant manner. The proposed system is demonstrated and evaluated in simulation, along with a live demonstration.

SYSTEM

- We consider package delivery as our example task, where the user specifies a delivery destination through a graphical user interface.
- Using the Google Maps API, a list of intermediate GPS waypoints are generated.
- The sidewalk navigation module moves the robot towards the next waypoint using either *group surfing* or *curb following*.

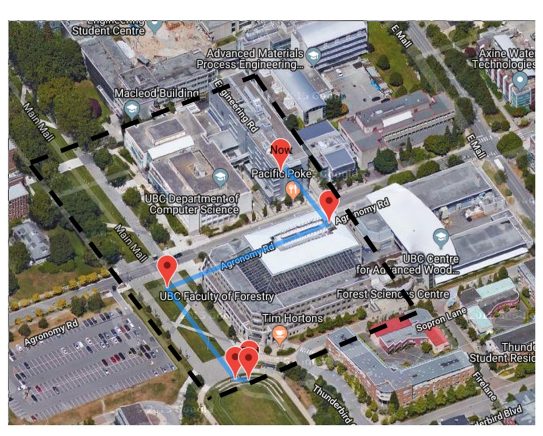


Figure 1. User interface with waypoints

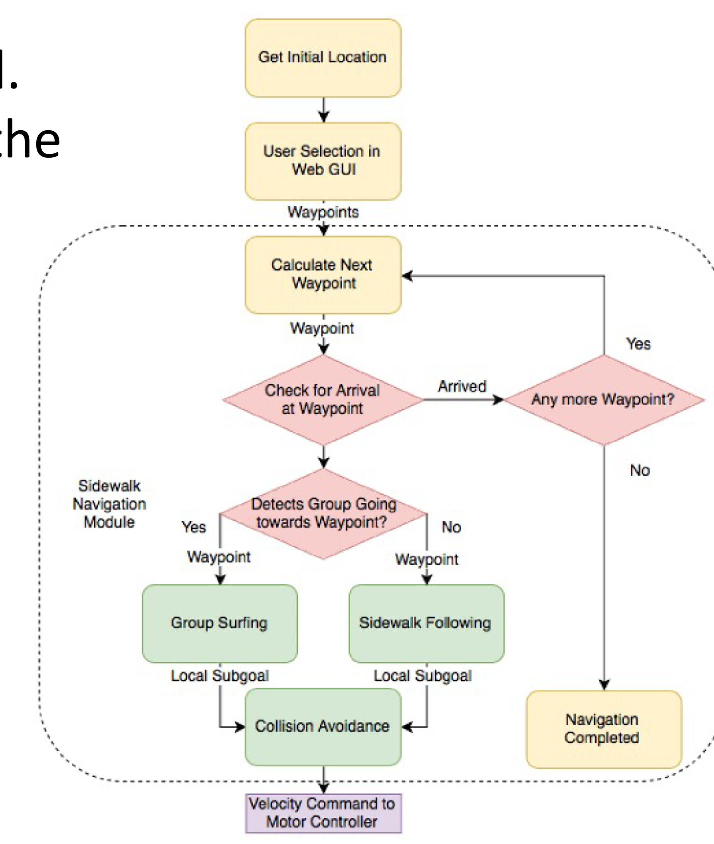


Figure 2. System flow diagram

GROUP SURFING

The group surfing algorithm takes advantage of natural pedestrian behaviors through imitation. Such behaviors include: walking in lanes, avoiding collisions with other pedestrians or obstacles, waiting at intersections to cross, and not walking into traffic.

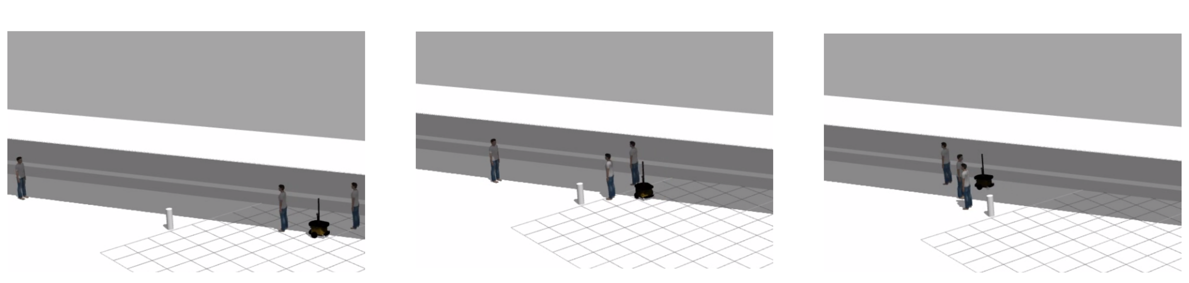
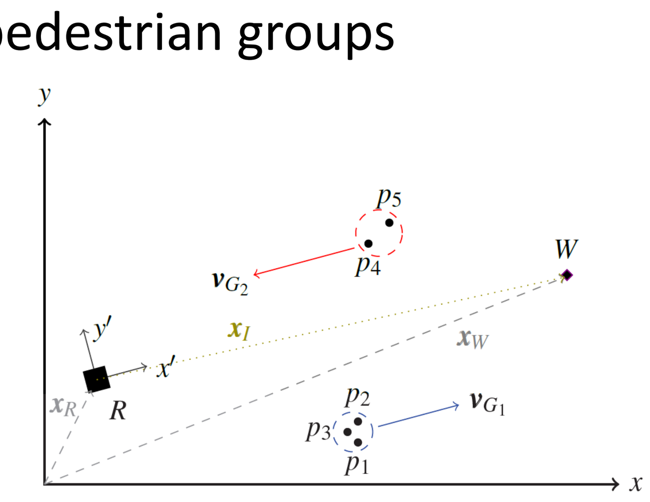


Figure 3. The robot is initially following a slower pedestrian, then moves to follow a faster pedestrian while avoiding the pedestrian walking in the opposite direction

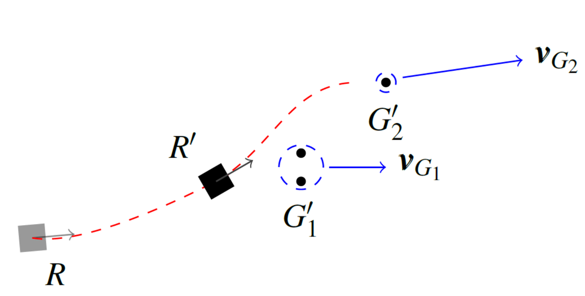
The two main steps taken in the group surfing algorithm are:

1. Identify and filter candidate pedestrian groups



$$\mathbf{v}_{G_i} \cdot \mathbf{x}_I > 0$$

2. Select a group to follow



$$\mathbf{v}_{G_2} > \mathbf{v}_{G_1}$$

LOCAL NAVIGATION AND COLLISION

For local navigation we used the Socially-Aware Collision Avoidance with Deep Reinforcement Learning (SA-CADRL) package. We did not train the policy ourselves, but used the results made publicly available[1].

The SA-CADRL policy, $\pi : \mathbf{s}_t \rightarrow \mathbf{a}_t$ maps the robot's state and observations to a velocity control command.

The reinforcement training process induces social awareness through social reward functions, e.g., staying to the right and passing on the left.

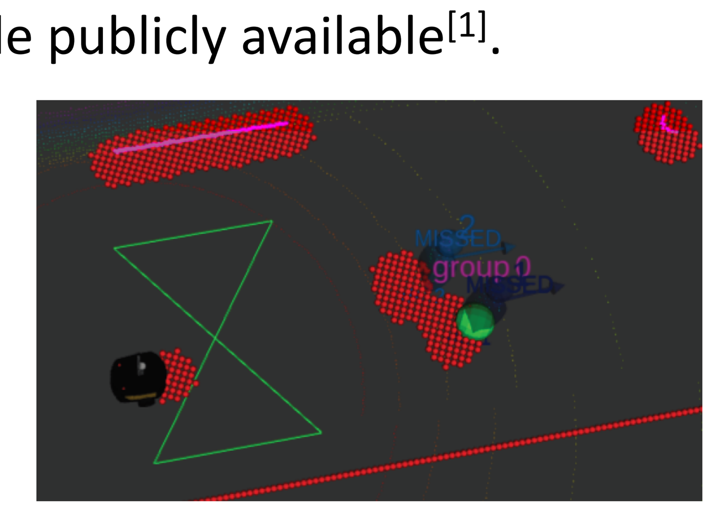


Figure 5. Group following and static obstacle avoidance.

[1] Chen, Yu Fan, et al. "Socially aware motion planning with deep reinforcement learning." *2017 IEEE/RSJ International Conference on Intelligent Robots and Systems*, 2017.

CURB FOLLOWING

When pedestrians are not in the field of view of the robot, the sidewalk detection navigation module is activated to allow the robot to follow the curb.

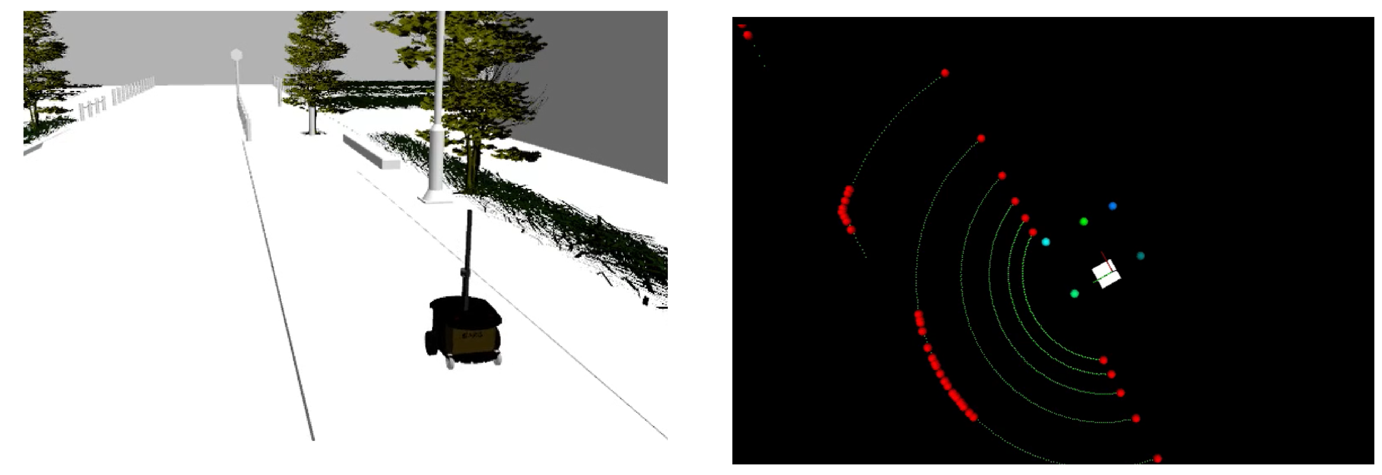


Figure 6. Curb detection and following.

To find the boundary between the sidewalk and the street:

1. The robot acquires a surrounding point cloud using a 3D laser sensor and filters the points on the street and fits a plane model.
2. Inlier points are projected into the calculate plane and a concave hull is estimated.
3. These points are used to fit a line that represents the curb and then estimate a local goal.

DEMONSTRATIONS AND RESULTS

In a simulated sidewalk environment populated with pedestrians, we compared the paths taken by a robot using our system (r_{path}), a simulated pedestrian (p_{path}), and the shortest possible path along the sidewalk (s_{path}).

	$h_{directional}$	$h_{average}$
r_{path}	1.9661	0.4726
s_{path}	2.3606	1.2195

Table 1. Comparison of directional Hausdorff distance and average Hausdorff distance between the path taken by a pedestrian and the path taken by the robot, r_{path}, and between the path taken by a pedestrian and the shortest path s_{path}. Both metrics are smaller for r_{path}, indicating that the path taken while using our system is closer to what a pedestrian would take – i.e. our system is more socially acceptable.

As a proof of concept, we implemented our group surfing method in the Powerbot and tested navigation on the same route that the simulated world was modeled after.

Figure 8. Group surfing navigation. A) The robot follows a pedestrian on the sidewalk. B) A second, faster pedestrian appears in the robot's field of view. C, D) The robot follows the second pedestrian to cross the road.

FUTURE WORK

- Further testing with different group sizes and sidewalk types to support generalizability of our method.
- The SA-CADRL is trained with simulated pedestrians; using real sidewalk pedestrian data may improve performance.
- Improve selection criteria for the group surfing algorithm.
- Interview external observers and pedestrians to gauge if the system produces socially acceptable behaviour.

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