Coursework 1: Wall Following with a LEGO Robot

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1 Introduction

We adopted a reactive approach to wall-following, for two reasons:

It is difficult to be sure where we are in the world We could not reliably follow the robot's movement through the world, as its proprioception (the ability for the robot to keep track of its body parts)[1] was weak; it could not say how far it had moved, even by counting the turns of its wheels. Skidding could make it go less distance than it believed, or its tyres could climb a vertical wall and believe it had travelled horizontally.

It is dangerous to assume what the world looks like Truly testing intelligence requires robots to exist in the real world. But we cannot produce valid intelligence by planning actions based on a representation of the world, since no representation could wholly represent the world[2]. Reacting is a more robust way to cope with a dynamic world.

For collision response, we recruited a mixture of avoidance and recovery. Our robot was designed to follow walls on the left only. It was largely blind on the right-hand-side, but invested a higher resolution in the side it was aiming to follow.

Avoidance An ultrasound sensor watched the left-hand-normal of the chassis. This was used to track distance to the wall it was following. The purpose was to ensure that the robot ran parallel to the wall, which had three applications: reducing the number of collisions to recover from (so that it could spend more time following the wall), maintaining known angle to wall (to compensate for lack of proprioceptory feedback from motors), and detecting when the wall has ended on the left (to initiate maneuver for continuing to follow it).

Recovery A bump sensor array was mounted in front of the robot. It was biased to covering the left-hand-side, as that was the side we were following (and thus most anticipating collision with). Collision with this would inform that a wall had been reached, and that it could be followed. The choice of recovery over avoidance for frontal collisions was because a bumper can physically resist further movement into the obstacle, simplifying the recovery. This is an example of how agent morphology generates its own sensory stimulation[3], and how valid intelligence requires a body[2, 3].

A subsumption architecture[2] complemented our reactive approach. It allowed lower layers (such as 'recover from collision') to inhibit immediate goals (such as 'follow wall'). This was critical for suppressing actions that were generating inappropriate behaviour. Sensors were all running, all the time, and created the impulse for action. In this way, our action was coupled to perception; our 'modules' were behaviours.

Ultrasound sensing was known to be noisy, so we did not initiate maneuvers based on single samples; a percentage of positive readings over some timeframe was required to produce a strong enough impulse to invoke action.

Overall the goal was to

2 Approach

The robot had three motors; two flanking on the rear, and one frontally in the middle. It was hoped that the extra motor could contribute to the robot's speed, especially during steering, where one flanking motor has to compromise its speed output to produce a turn.

The robot was told to begin by walking forward until a collision occurred. The first object it touched was considered 'the wall', and its goal was to keep that wall on its left, and follow parallel to it. The 'following' consisted of constant range comparisons between current distance and historical distance. If distance from wall was increasing over time, the robot recognised that it was diverging from the wall, so biased its flanking motors to steer toward or away from the wall, maintaining a parallel angle. This fine correction of steering was called 'pronation'.

In the case of a right-turn in the wall, a frontal collision was expected to be sensed by the bump sensor, and a 'face right' three-point-turn primitive was used to face its right-hand normal. In the case of a left-turn in the wall, a continuous reading of 'distance_max' from the left-hand sensor was expected, and a left three-point-turn primitive was used to turn into the space. Overshooting or undershooting the turn did not matter (whether because the maneuver failed or because the wall was not perpendicular), because pronation corrected the robot's angle to the wall. Pronation also tried to achieve an optimal berth from the wall; convergence toward the wall would be initiated if the robot was detected diverging from the wall, or if the robot was too far from the wall. 'Optimum' distance was defined as a band of ranges that were 'far enough to prevent collision with left wall', but 'close enough that the followed wall was not mistaken for 'distance_max''.

Behaviour inhibition was implemented by modeling maneuver primitives as queues of motor outputs, to be popped on each timestep. Sensors ran every timestep also. Thus if a bump was detected during a maneuver, the motor queue could be cleared, aborting the maneuver in favor of a newer, more appropriate action. Layering was achieved by giving each sensor a priority; for example, bumping required urgent recovery, so could interrupt any other behaviour. The overarching 'wall-following' behaviour was an implicit, emergent layer that was achieved by subsuming all lower behaviours whenever sensors deemed appropriate.

Overall the robot was optimized for reaction at speed; its architecture allowed it to interrupt maneuvers. Its full complement of motors allowed it to make fine steering adjustments without compromising speed. Its static sensor mounting meant that sensing was immediate, and not a bottleneck on choosing action. Its pronation behaviour enabled it to maintain a predictable position in a changing environment, and one designed to reduce collisions so that it could spend less time recovering from them.

We evaluated part of our robot's reaction effectiveness, by measuring its pronation effectiveness. Since the goal was to stay parallel to the wall, we measured how quickly it could achieve a parallel angle after rounding a corner, and how parallel that angle was. This angle change was measured by placing an array of rulers along a wall, reading what distance the robot was from the wall as it passed each one, and using trigonometry between those values to measure angles. As an independent variable, we varied the angle around which the robot had to turn to meet the new wall (ie, how obtuse the two walls were).

Use p values?

3 Results

The results section describes the outcomes. This should be purely factual descriptions, including qualitative outcomes, quantitative outcomes and possibly statistics. For example, you could report the average speed around a circuit in two conditions plus standard deviations and a significance test to tell whether you have evidence that the conditions lead to different results. *For coursework 1, this must include video.* Typically, the results section can be surprisingly short, since the Approach section is the one giving details, this is purely and only factual outcomes.

With respect to your own results, if you describe a reasonably-well working system in a comprehensible manner you will pass. If you competently fill in all of these sections as described in this specification, you will get at least 55. Getting a mark over 70 requires demonstrating insight, creativity and / or understanding that goes beyond the basics laid out for you in this document. For example, an insightful comment about one or more cited papers supported by evidence from your experience might get you these extra marks. So might a particularly accurate and replicable account of your approach and results.

4 Discussion

The discussion is the most discursive part of your paper, it *may* include speculation. You should discuss the extent to which your results addressed the questions described in your introduction, and what the results imply about your own work and work more broadly. You might suggest other experimental protocols that could have given different results and lessons learned. This can be a longer section as well.

5 Conclusion

The conclusion is just one paragraph. After possible digressions in the discussion, you should come back to state exactly what you tried to do (brief summary of the introduction), what the outcome was (brief summary of the results), and what you can certainly state as a result of this (the implications of the results in light of the introduction.)

References

[1] Shannon Lee. *Proprioception: how and why*. 2002. URL: `http://serendip.brynmawr.edu/exchange/node/1699` (visited on 03/02/2014).

[2] Rodney A Brooks. “Intelligence without representation”. In: *Artificial intelligence* 47.1 (1991), pp. 139–159.

[3] Rolf Pfeifer and Fumiya Iida. “Morphological computation: Connecting body, brain and environment”. In: *Japanese Scientific Monthly* 58.2 (2005), pp. 48–54.