Legible Motion for Service Robots

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1 Proposed Contributions:

1.1 Contrib (1): Modeling Visual Perceptions

The concept of legibility against predictability of robot behavior was initially introduced by Dragan et al. [**?**]. Even though in the original paper, the authors did not go beyond a general notion of the observer, and did not consider how the robot's behavior can be perceived by the observer, there have been a few steps in recent years to address this gap. For instance, Nikolaidis et al. [**?**] extended this work by introducing considerations of viewpoint and projecting the motion on the observer's image plane, Furthermore, they formulated solutions for handling occlusion scenarios. Taylor et al. [**?**] sought to incorporate the observer's field of view into the legibility computation. They also, considered a scenario with multiple observers, and proposed a way to compute the legibility of a motion for each observer. But there is still a gap in the literature, in addressing the visual inputs of a human observer for computing legibility. In this work, we propose a new approach for computing the motion legibility by considering visual factors from the observer's perspective.

Example: Let's imagine a scenario where a service robot is delivering a drink to a table in a restaurant. And the robot wants the observer to know that it is going to the table, and not to the other tables in the restaurant. Based on Dragan's definition, the robot should choose a trajectory that maximizes the prediction of the right goal for the observer. And the robot should do this maximization at the beginning of the motion, due to the $f(t)$ term, in the legibility function [REF], that encourages the robot to maximize the legibility at the beginning of the motion. But we know if the target person does not pay attention to the robot, this is not a good effort, and it might just sacrifice its efficiency, without any gain in legibility.

A model that consider the observer's field of view or the obstacles, do not perform any better, because the motion is still happening in the observer's field of view, and the observer can see the robot.

In this work we propose to compute the motion vectors of the robot from the observer's perspective, and use this information to compute the legibility of the motion.

1.2 Contrib (2): Synthesis

The second contribution of this work is a new approach to generate legible motions for mobile robots. In fact, the problem of generating legible motions for mobile robots has not received as much attention as the evaluation. For example, in several works legible and illegible trajectories were manually designed by the authors, or handcrafted to collect the user study data [REFs]. And in [Ada-RO-MAN2022] the paths were selected via a sampling approach.

From [X] we know that optimizing the legibility function directly is not always possible. This is because that $\Delta\mathbf{L}(\xi) = 0$ or $\mathbf{L}(\xi) = 1$ might not have a solution in the finite space. For this reason, we might need to add some constraints to the equation to make it solvable. In the original work, Dragana et al. [X] this is done by adding a regularizer that discourage increasing the path length. $L(\xi) = legibility(\xi) - \lambda C(\xi)$ where $C(\xi)$ is the path length, and λ is a constant. Also, Dragan and Srinivasa [X], introduce a trust region constraint on the optimization to ensure the motion does not become too surprising or unpredictable to the observer. This approach in the end, turns to finding a good value for a parameter β, using a user study. Moreover, due to the iterative nature of this approach, it can compromise the real-time performance of the system.

In this work, we propose to use artificial potential fields to directly generate legible motions for mobile robots. We show that this approach can improve the time performance of the system, and can generate legible motions in real-time. Our formulation takes into account the final pose of the robot at the end of the motion, and introduces new force fields to encourage legibility of robot motions.

1.3 Contrib (3): New metrics

(a) Absolute Envelope of Readiness: We introduce a slight modification to the envelope of readiness metric proposed in [REF], since the original metric is bound to a coefficient that is not generalizable to different scenarios. Here,

we remove the 5% tolerance from the metric, and we call it the absolute envelope of readiness.

2 References

1. Legibility and Predictability of Robot Motion

2. Observer-Aware Legibility for Social Navigation

3. Generating Legible Motion

4. Viewpoint-Based Legibility Optimization

5. A new approach to evaluating legibility: Comparing legibility frameworks using framework-independent robot motion trajectories

6. A flexible optimization-based method for synthesizing intent-expressive robot arm motion

7. A MIP-Based Approach for Multi-Robot Geometric Task-and-Motion Planning

8. Wait Wait, Nonverbally Tell Me: Legibility for Use in Restaurant Navigation