# Quantitative Metrics for Execution-Based Evaluation of Human-Aware Global Motion Planning

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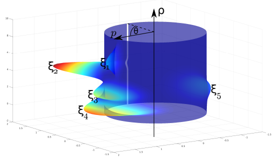

Fig. 1. One instance of an MoD representation: the CLiFF-map [5] encodes motion patterns using a set of semi-wrapped Gaussian mixture model.

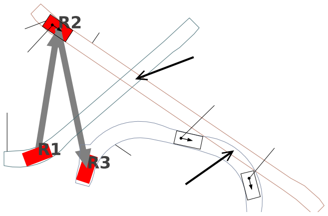

Fig. 2. Simulating human–robot interaction while playing back real-world pedestrian data using the coordination_oru framework [7].

How well a robot adheres to social norms is a crucial factor in the acceptance of robots. Making robots aware of motion patterns exhibited by people can be beneficial in this sense. Let us consider a robot operating in a tight corridor alongside people. A human-aware robot would plan paths along the flow of people in order to avoid forcing people to manoeuvre around the robot or vice versa.

Over the years several different representations have been developed to model dynamics in environments. For simplicity we call these Maps of Dynamics (MoDs) [4]. With respect to mapping the motion patterns of people, these methods can be broadly classified into three groups: trajectory mapping [1], velocity mapping [5, 9], and mapping of spatial configuration changes [3, 6].

Global motion planning is the phase of mobile robot motion planning that happens before the robot starts moving. It constitutes a general plan (i.e. a sequence of motions to execute) that a robot should use to reach the goal pose from its current pose. Thus, MoD may positively impact global motion planning through *enabling the robot to plan paths that complies with the implicit traffic rules and are along less congested regions*. This is expected to lead to less intrusive motions around people, therefore leading to less reactive replanning and also effectively reducing the ‘freezing robot’ behaviour. In consequence, an MoD-aware planner is expected to lead to time-efficient motions: less time is wasted in reactive replanning and execution of motions. To the best of our knowledge, *there are currently no studies* of the actual effects of executing dynamics-aware motion plans in the literature.

In our previous work [8], we developed a motion planner that uses MoD information and showed that it can be tuned to follow or avoid observed flows, depending on application requirements. However, the evaluation scenarios were simplified to demonstrate advantages of the MoD-aware planner. We used a synthetic environment and only evaluated the generated paths themselves, and not the effects of executing the plans in actual flows of people.

We believe that in more complex scenarios, to assess the impact of MoDs on quality of paths the traditional metrics (path length, curvature, roughens) are not sufficient and it will be necessary to test the actual execution of MoD-aware paths. It is non-trivial to assess whether a plan generated using one type of MoD is better than a plan generated using another. Recall that our motivation for employing MoDs is so that the robot can avoid extra manoeuvring around approaching persons, and hence, save time. Therefore, we would like to know: will a robot save time if it employs MoDs in motion planning?

In this work, we extend the ideas motivated in our previous work. We use real pedestrian data – the ATC Mall dataset [2] – to build the MoDs. In this paper, as opposed to metrics on the solution paths alone, we also use quantitative metrics related to *execution* of the those paths while interacting with people.

We propose two metrics over execution of MoD-aware global plans. We do this by limiting the robot’s reactive behaviour as follows: the robot pauses when a human is in the vicinity and continues executing the global plan once the human has passed. In this manner we can compute the total time spent by the robot waiting for humans. We can also compute the total number of times a robot has to wait: the number of times a human is in its way. The same can be done if the human waits instead of the robot.

In addition to experiments with people, we also propose to use a multi-agent coordination framework [7] as a proxy for simulating the aforementioned behaviour (see Fig. 2). Here, we can play back recorded pedestrian data while allowing the robot to execute its motions. The coordination framework allows us to define precedence constraints: if the paths of two agents intersect, who should go first. Either the robots or humans can be given exclusive precedence. For example, if we wish to simulate an *adamant-robot* behaviour, we simply give the robot precedence and humans would stop at intersections allowing the robot to pass first. The simulated humans would then continue along their path respecting the velocity profiles in the recorded data. This allows us to evaluate and compare the effectiveness of executing different MoD-aware motion plans in simulation.

In summary, we define objective metrics for evaluating human-aware global plans. We also propose a method to conduct experiments in simulation using a coordination framework while using real pedestrian data and making reasonable assumptions. Finally, we present a comparison of different MoD-aware global planners based on the metrics we propose.

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