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Advanced Velocity Planning for Robotic Systems

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***Abstract*—Many industrial tasks (*e.g.*, welding) require advanced velocity planning to achieve the target final product quality. In this paper, a novel approach is proposed to perform robotic trajectory planning. The developed algorithm exploits Fuzzy Logic (FL) to relate path features (such as curves or sharp edges) to the proper execution velocity. Such a computed velocity reference is then used as an input for Dynamical Movement Primitives (DMP), providing the reference signals to the robot controller. The main improved methodology features are: path-based velocity planning, extension of DMP to variable velocity reference, the smoothing of the velocity reference including robot velocity/acceleration limits.**

***Index Terms*—Autonomous robotics, collaborative robotics, DMP, Fuzzy Logic, trajectory planning.**

I. Introduction & related works

Within Industry 4.0 paradigm, robots must be able to learn/perform a reference task, exploiting autonomous planners for motion generation. Such topic is critical in many applications, like sealing and welding, where execution velocity is the control objective. Trajectory planning is a hot-research topic. [1] finds the optimized motion for both robot end-effector and joints for welding robots, but it doesn't set the velocity along the path. In [2] a sealing task is done using global planning interpolation and trapezoidal speed profile, but without considering any coupling and variable velocity. In [3] DMP are assessed for movement sequencing trajectory planning employing velocity continuity between blocks.

A. Paper Contribution

Taking as a reference an automatic sealing task (within H2020 CS2 ASSASSINN project), the here presented contribution aims to design a trajectory planner able to generate the robot's reference motion to properly manage the sealant deposition. The task execution velocity, which strongly affects the material deposition, is the design and control main parameter. The velocity reference has to be managed considering the deposition path, taking into account its geometrical features (such as sharp edges, curves, etc.) to avoid a surplus/shortage of sealing material during the deposition. The described trajectory planning problem must consider both geometrical path features and hardware limitations (robot velocity/acceleration limits). The here presented paper proposes a combination of FL and DMP methodologies. The FL relates path features to the proper execution velocity. The computed velocity is then used by the DMP, providing the reference signals to the robot controller. While the FL methodology has been selected due to its capabilities in automatic I/O mapping [4], DMP were selected due to their capabilities for trajectories representation and time/space scaling [5]. Simulation and experiments have been performed, highlighting the trajectory planning capabilities of the proposed framework, considering a complex reference path.

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II. Methodology

The proposed approach, combining FL and DMP, is depicted in Figure 1. From the reference path $\mathbf{y}_{des}$ the *steer* parameter is computed as follows (Figure 2):

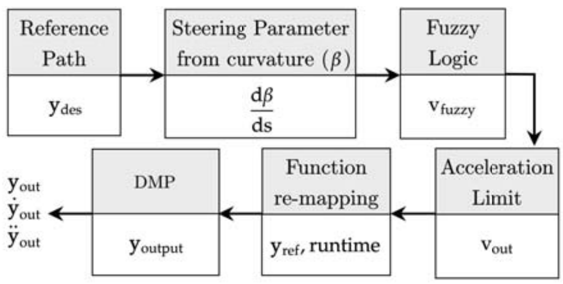

Fig. 1: Trajectory planning framework.

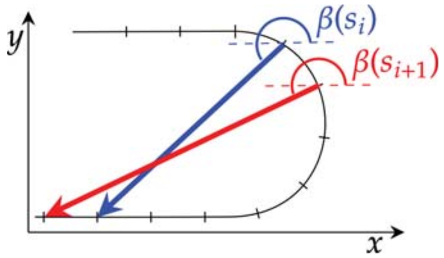

Fig. 2: Example of vector definition during a path curve. In the example: n = 7.

- vector $v_{i,i+n}$ is defined, connecting the considered path point with another one n steps forward;
- vector $v_{i+1,i+1+n}$ is defined, connecting the next point with the $n+1$ steps forward point;
- angles $\beta(si)$ and $\beta(si+1)$ are computed (between the horizontal axis and $v_{i,i+n}$ / $v_{i+1,i+1+n}$, respectively);
- the difference between $\beta(si)$ and $\beta(si+1)$ defines the *steer* parameter.

The absolute value of the *steer* parameter is used as an input to the FL. The FL relates the reference velocity to the path geometry, modulating the task execution managing velocity limits. The FL planned trajectory is corrected accordingly to the robot acceleration limits, relaxing the time vector: if the acceleration limits are overcome, a time-shift is added to the planned trajectory to satisfy acceleration constraints (Figure 3). The corrected trajectory $\mathbf{y}_{ref}$ is finally used as an input to the DMP framework, smoothing noise and giving continuity to the velocity profile. The DMP also allows to define a human-robot collaborative framework by embedding a compliant controller to manage external interactions and to perform trajectory error recovery.

III. Results

The proposed framework has been successfully tested on a Franka Emika Panda robot. The numerical results related to $\mathbf{y}_{out}$ (output of the DMP) are shown in Figure 4. It is possible to highlight the correlation between the velocity profile and the path features: w.r.t. standard DMP, a variable velocity is achieved along the path.

IV. Conclusions

The presented paper proposes a framework for trajectory planning, being able to take into account geometrical path features and velocity/acceleration limits. The planned trajectory shows an execution velocity that is dependent on the geometrical path characteristics, making possible to manage the target task. While the here presented trajectory planning is performed offline, the proposed DMP framework is now under implementation for real-time trajectory planning, embedding a compliant controller into the DMP framework to manage external interaction (e.g., for human-robot collaboration purposes).

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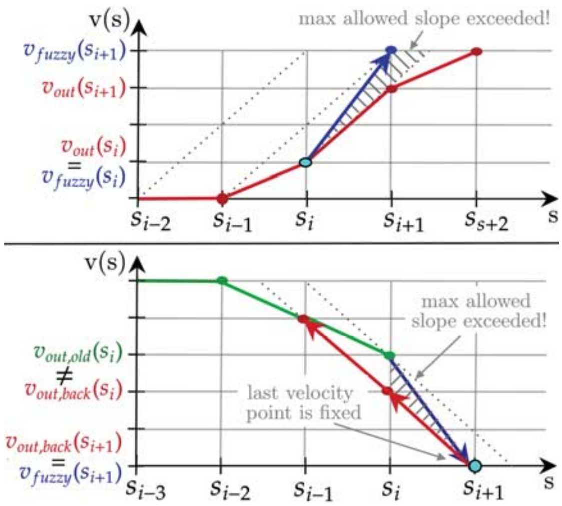

Fig. 3: time-shift for the acceleration limit: in blue & green the computed v(s) that exceeds the limit is shown, while in red the new (feasible) velocity reference is highlighted.

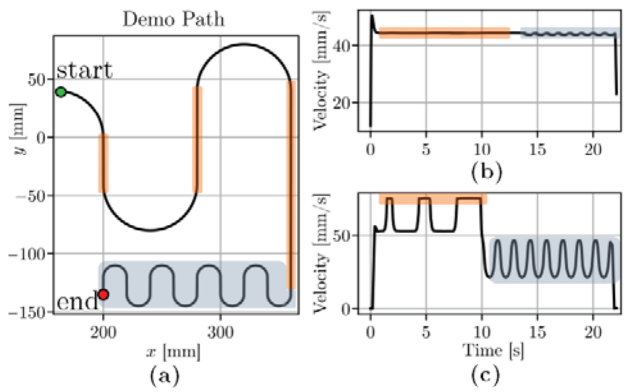

Fig. 4: Two different executions of the path shown in (a): in (b) the output velocity from a classical DMP formulation is presented, while in (c) the newly proposed method permits a continuous modulation of the velocity reference.