KHAOS Improvements Using BSpline

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Abstract: The introduction of BSpline to generate the trajectories for a Kinematic Human Aware Optimization-based System for Reactive Planning of a Flying-Coworker, a multi-rotor drone that collaborates with workers to fetch small objects, is presented. This allows to improve the quality of the motions and helps to better respect the constraints relative to the collaboration with a human.

1 INTRODUCTION

In our previous work, we presented KHAOS (Truc et al., 2022), a Kinematic Human Aware Optimization-based System for Reactive Planning of Flying-Coworker in the context of the "Flying Co-Worker" project: a multi-rotor drone that collaborates with workers to fetch small objects. The robot must fly in a human-populated area, where only a handful of human workers may be "aware" of the robot's current task and mission, and a fraction of them may be involved in the physical interaction (e.g., object delivery): the robot must assume that most humans are "observers", i.e., they ignore its current mission and are not involved with it. In such conditions, the drone needs to carefully plan its 3D motion in a reactive way to navigate and act safely in close proximity to humans. Beyond safety, the drone should aim at exhibiting navigation strategies that are, as much as possible, socially aware: for example, it should avoid fast movements that could scare the observers; it should maximize its visibility (Sisbot et al., 2007) for workers, especially when engaging in an interaction. To address the navigation requirements mentioned above, we proposed KHAOS for reactive planning, which produces trajectories in the 3D space satisfying the kinematic constraints of the drone and ensuring the visibility and ease of the humans present in the environment. The human-aware behavior is realized by proposing a visibility cost and a novel discomfort cost and including these along with the kinematic constraints into a stochastic optimization process inspired by the STOMP algorithm (Kalakrishnan et al., 2011).

In this paper, we first show the benefits of an extension of Softmotion (Sidobre and Desormeaux, 2019) using BSpline as input to KHAOS to smooth the initial path. Then, in two different scenarios, we show the interest of using BSpline to improve the trajectories generated by KHAOS and to ensure that they are feasible.

2 INITIAL PATH SMOOTHING

STOMP algorithm optimize an initial path from a set of costs to generate a new smoothed path. This smoothing is dependent on the initial path, indeed STOMP does not allow to smooth the too important breaks of the initial path. These breaks will remain in the final result and may even be amplified. By inheritance, KHAOS suffers from the same problem and thus requires smoothing the initial input path in order to obtain a satisfactory output. Moreover, it generates a 3D trajectory constrained by kinematic limits (bounded velocity, acceleration and jerk) and human-aware costs that can also have an impact on the kinematic parameters. This trajectory must therefore respect the feasibility from a kinematic point of view by avoiding, for example, too sharp turns that would force the robot to slow down during execution.

To this end, we propose the use of the SoftMotion library and in particular an extension of the well known Non Uniform B-Spline (Piegl and Tiller, 1996; Rousseau, 2019) to generate feasible trajectories from a list of waypoints. The main advantage of this extension is to allow the control of the kinematic pa-

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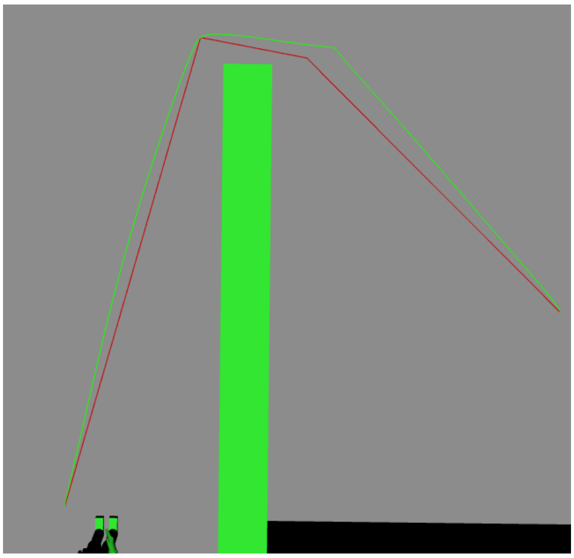
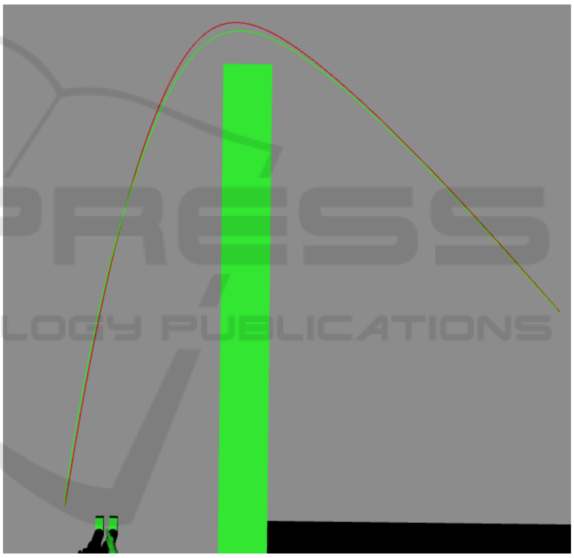
rameters at the beginning and at the end of the trajectory, which is necessary to ensure continuity between consecutive trajectories generated by two successive plannings. Many planners such as PRM or RRT allow to generate an initial path connecting a start point and an end point. Between each waypoint composing this initial path, we have segments that by nature do not allow to respect a continuity. The use of BSpline will allow to generate a smooth trajectory from this list of waypoints even when they are numerous and very close. In Fig.1, We compare the outputs of the standard version of KHAOS when no smoothing is applied (Fig.1a) and when a B-Spline is used (Fig.1b). When no smoothing is performed, we show that even after many iterations, the continuity defects present in the initial path are transmitted to the KHAOS result. On the other hand, when using B-Spline, we can observe that the trajectory generated by KHAOS is very smooth too. This allows our algorithm to start on a good basis and will facilitate the optimization phase because naturally the continuity will be respected.



(a) Standard KHAOS.



(b) KHAOS using BSpline.

Figure 1: Shapes of the initial path (red) and trajectory generated by KHAOS (green) after several iterations for two cases: a) when no smoothing is applied to the initial path and b) when BSpline are used to smooth.

3 KINEMATIC COMPLIANCE

In addition to smoothing and giving a harmonious shape to the trajectory, this SoftMotion extension allows, from the list of waypoints from KHAOS, to ensure continuity from a kinematic point of view but also to respect the human-aware constraints. Indeed, KHAOS provides the position and speed for each waypoint according to constraints adapted to humans in the environment but also considering the kinematic limits of the drone. For example, if the drone starts far enough from any human and outside its visual field, it will accelerate to its maximum speed at maximum acceleration (Fig.2 between 0 s and 2 s). When it is close enough to a human, the human-aware costs will become important. When approaching a human, for a handover for example, the drone will undergo a deceleration (Fig.2 between 8 s and 14 s) dictated by the human-aware costs but KHAOS also verifies that this deceleration is achievable by the drone considering its deceleration limits. If it is not feasible from the kinematic limits point of view, KHAOS will generate a trajectory where the drone will slow down earlier so that it is feasible and that the human-aware constraints are also respected.

We wish that between each of these waypoints (segments), the respect of these constraints is ensured. For example, in order not to cause too much discomfort to humans in the environment, KHAOS makes sure, among other things, to limit the speed according to the distance to the human. It is therefore necessary to be sure that between two positions provided by KHAOS, the speed along the segment is in agreement with the speeds given at each of these two positions. If we look for example at the KHAOS curve not using BSpline (Fig.2 in green), we notice around 1.8 s and 8 s, sharp changes if we consider simple line segments connecting the waypoints. These defects are corrected by using the BSpline (Fig.2 in orange), allowing on the one hand to ensure that it is physically feasible by the drone, but especially to obtain a more fluid movement and therefore less uncomfortable for the human present in the vicinity.

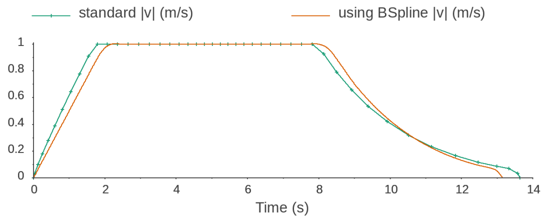
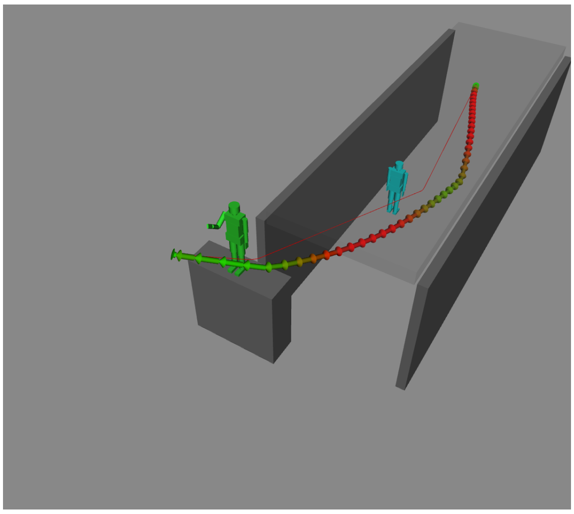
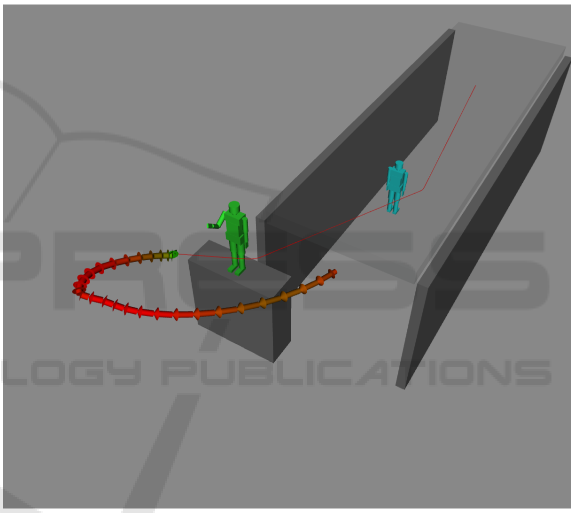


Figure 2: Magnitude of the drone's speed before (green) and after (orange) using BSpline in the KHAOS output in the scenario where the drone approaches a human from the front in a straight line.
The time bases do not match between the two curves because the calculation of the times is different between the calculation of the waypoints and SoftMotion.



(a) Start trajectory.



(b) Later trajectory.

Figure 3: Trajectory execution in a two-humans scenario. a) First trajectory generated by KHAOS, the drone starts by navigating in the corridor. b) A few iterations later, after passing the blue human in the corridor. *Red line: represents initial path before smoothing using BSpline. Red arrows: highest speed magnitude. Green arrows: lowest speed magnitude.*

4 TWO HUMANS

We take the example of the corridor with two humans presented in our previous paper (Truc et al., 2022). The objective for the drone is to navigate from one end of the corridor (Fig.3a), pass the human in blue, then arrive from the back of the human in green (Fig.3b) in order to position itself in front of him as if it wanted to exchange an object with him. We show in Fig.4, the magnitude speed profile along the trajectory actually executed by the drone by concatenating the trajectory portions generated at each iteration of KHAOS. Indeed, another advantage of our SoftMotion extension, is to generate trajectories from a non-zero speed and acceleration set-point needed as input by KHAOS in a reactive planning context. In the situation presented here, the human-aware constraints as well as the environment of the corridor constrains the trajectory of the drone, forcing it to pass close to the human in blue and thus reduce its speed (Fig.4 between 3 s and 13 s), once out of the influence of the first human, it can accelerate again. Once it gets close enough and in the back of the human in green, it must slow down again (Fig.4 between 15 s and 20 s) and turn around the human to appears in the human visual field before finishing its approach. We can notice how the speed profile is smoothed when the drone approaches the speed limit, or when it has to make a sharp turn (around 20 s).

5 CONCLUSIONS

The use of BSpline is a real gain for KHAOS, allowing our algorithm to propose more realistic trajectories that can be directly used by a basic controller. As we have shown, this makes it possible to improve the initial path at the input of KHAOS and also to ensure to provide at the output a trajectory achievable by the drone and respecting the human-aware constraints even better. From the human-aware point of view, it also improves the behavior of the drone whose movements are more fluid and cause even less discomfort than with the standard version. We also presented in our scenario with two humans, the final result of a tra-

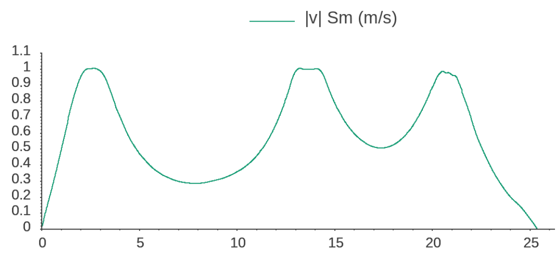


Figure 4: Magnitude of the drone's speed using BSpline composed of many iterations of KHAOS in the scenario with two humans.

jectory executed by the drone and composed of many iterations of KHAOS, showing the ability of our Softmotion extension to generate BSpline resuming the non-zero speed and acceleration set point of the previous iterations. In the near future, we want to improve this extension of SoftMotion by adding an optimization step to further refine the kinematic parameters. Also, we plan to explore the possibility of implementing the use of BSpline directly in the core of KHAOS, in order to work directly on feasible trajectories at the optimization level.

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REFERENCES

Kalakrishnan, M., Chitta, S., Theodorou, E., Pastor, P., and Schaal, S. (2011). STOMP: Stochastic trajectory optimization for motion planning. In *2011 IEEE International Conference on Robotics and Automation*, pages 4569–4574, Shanghai, China. IEEE.

Piegl, L. and Tiller, W. (1996). *The NURBS book*. Springer Science & Business Media.

Rousseau, G. (2019). *Optimal trajectory planning and predictive control for cinematographic flight plans with quadrotors*. PhD thesis, Université Paris-Saclay.

Sidobre, D. and Desormeaux, K. (2019). Smooth cubic polynomial trajectories for human-robot interactions. *Journal of Intelligent & Robotic Systems*, 95(3):851–869.

Sisbot, E., Marin-Urias, L., Alami, R., and Simeon, T. (2007). A Human Aware Mobile Robot Motion Planner. *IEEE Transactions on Robotics*, 23(5):874–883.

Truc, J., Singamaneni, P.-T., Sidobre, D., Ivaldi, S., and Alami, R. (2022). Khaos: a kinematic human aware optimization-based system for reactive planning of flying-coworker. In *ICRA 2022*.