SAPHARI

SAFE AND AUTONOMOUS PHYSICAL HUMAN-AWARE ROBOT INTERACTION

SEVENTH FRAMEWORK PROGRAMME

COGNITIVE SYSTEMS & ROBOTICS

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Reactively adaptable motion plans for real-time collision avoidance

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Executive Summary

This deliverable of workpackage WP6 reports on the methods we developed to tackle the problem of reactively and efficiently adapting robot motion plans in the vicinity of humans and where performing collaborative tasks with them. Another constraint is as much as possible considering safety of course but also acceptability and legibility of the robot behavior.

As expected, there is no one approach or method that encompasses all cases. We have investigated, developed and implemented several methods and schemes that clearly go towards the overall objective.

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Introduction

In WP6.1 we intend to develop methods for generating adaptable motions. The first part of this task deals with adaptive motion plans, which are needed to perform task re-planning in case of environmental changes that force such actions. Indeed, despite the recent progress of sampling-based planners, motions for complex robots performing tasks in real-world settings are still a challenge, especially in the context of human-robot collaborative tasks for which the robot has to reactively adapt to environmental changes and to the human actions.

This deliverable of workpackage WP6 reports on the methods we developed to tackle the problem of reactively and efficiently adapting robot motion plans in the vicinity of humans and where performing collaborative tasks with them. Another constraint is as much as possible considering safety of course but also acceptability and legibility of the robot behavior.

As expected, there is no one approach or method that encompasses all cases. We have investigated, developed and implemented several methods and schemes that clearly go towards the overall objective.

We describe in the following the methods and schemes which have been developed.

Trajectory deformation techniques for human-aware path planning

The classical way of solving motion planning consists of generating a collision free geometric path that is then treated to account for dynamic constraints before being executed by the robot controller. With the presence of humans in the workspace, it is important to account for additional constraints such as safety and legibility [Sisbot08] of the motion in addition to the feasibility constraints (i.e. non collision and dynamic constraints). Besides, in order for the robot to be as safe as possible it must account for the human motions.

In previous work we have applied sampling-based techniques to compute human-aware robot paths in possibly cluttered environments using the T-RRT method [Mainprice11]. However due to the global cost space exploration, this approach is not capable of real-time collision avoidance. Hence we have investigated in [Mainprice12] its combination with an anytime trajectory optimization technique which is briefly described below.

Path deformation provides a good framework to adapt and reuse previous plans. Additionally, such techniques present anytime properties which make them suited for real-time collision avoidance. Recently, two algorithms [Ratliff09, Kalakrishan11] were introduced which deform an initial trajectory that may be in collision with obstacles. They proceed by improving the input trajectory regarding control and collision costs. Because they produce smooth trajectories they do not necessitate the smoothing stage common to sampling-based approaches.

We have investigated the adaptation of the stochastic trajectory optimization for motion planning (STOMP) algorithm [Kalakrishan11]. Contrarily to CHOMP [Ratliff09] it does not require the gradient of the objective function. It iteratively optimizes a discretized trajectory composed of N waypoints by combining noisy trajectories in an update, which is then applied to the current trajectory. Each configuration cost along the noisy trajectories is evaluated and the higher the cost, the smaller will be the configuration contribution to the noisy update. Figure 1 shows 10 noisy trajectories that are evaluated around a human. Once the update is computed, it is smoothed by propagating each contribution along the trajectory resulting in safer and smoother updates. This stochastic gradient estimation is motivated by the limitations of gradient based optimization when it comes to non-differentiable or non-smooth cost functions, it is inspired by previous work in the area of path integral reinforcement learning.

The initial implementation aimed to minimize collision cost regarding a 3D distance grid computed over the workspace. A colliding configuration had a cost proportional to the amount of penetration while a collision free configuration had a null cost. We have adapted this method to HRI constraints by combining this cost to one proportional to the relative to the distance between the human and the robot and how much is the robot visible. This results in a richer cost landscape to be explored. Hence the case of optimizing a collision free trajectory that is the output of an RRT algorithm has been investigated. However the combination poses a problem. In its original version STOMP is initialized with a straight-line trajectory with low control costs (i.e. acceleration along the trajectory). On the other hand, RRT solutions are broken line segments smoothed in an optimization phase. We have investigated several solutions to initialize STOMP from an RRT solution such as adding waypoints to the segment extremities or changing the gradient propagation before the update. However we found that limiting the control cost with a smoothing stage using the traditional shortcut resulted in a more efficient solution. Combining both techniques enables to find paths in cluttered environments by using STOMP to locally enhance the path regarding the HRI constraints. Figure 2 and 3 show trajectory examples that are generated with RRT alone and then the combination of T-RRT (a cost-based RRT variant [Jaillet10]) and STOMP.

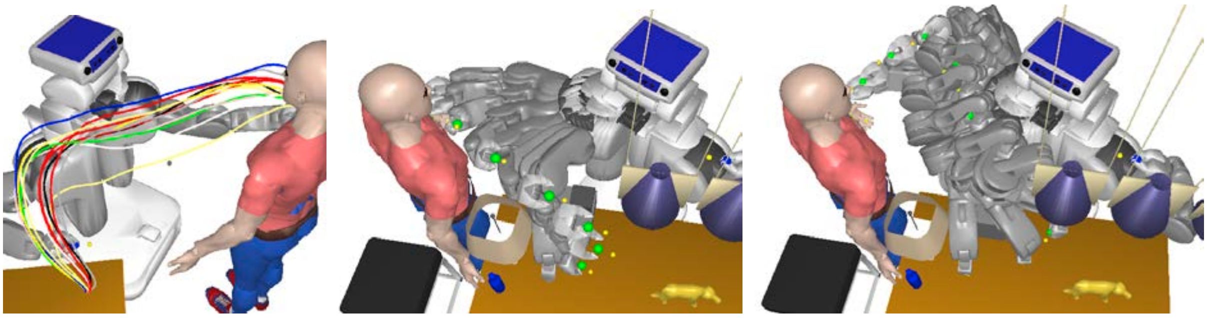

Figure 1: use of STOMP to adapt a human-aware path, taking into account safety (distance) and legibility costs

A scheme to integrate and use in a pertinent way several levels and types of reaction

This year we started the investigation of a global scheme intended to determine what action the robot should perform. Indeed, a survey that we published and a user study that we have conducted in the framework of the SPENCER project allowed us to exhibit that a too reactive robot behavior, particularly when it is very close tot he human, might induce confusion.

Based on this we propose a scheme which integrates:

- Continuous evaluation of the quality (comfort, legibility) of the current path taking into account not only the current context but also anticipated human motion
- A first level of speed adaptation along the current path (slow down, wait, restart or accelerate)
- A second level of path adaptation or (re)planning

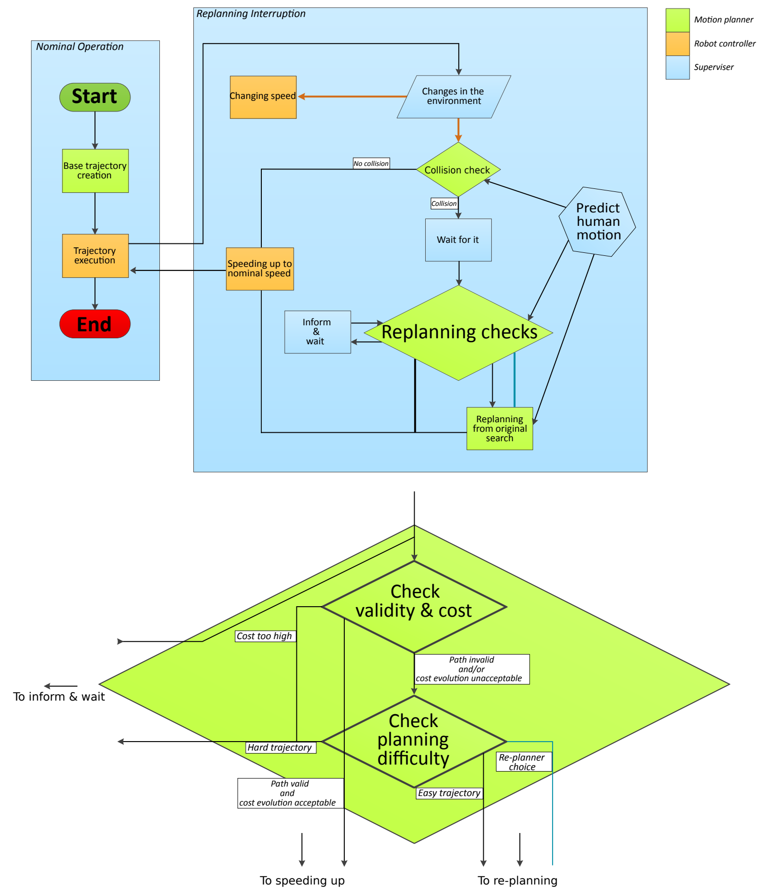

Figure 2: scheme for adapting speed, continuous evaluation of current path and re-planning

Only in the two "slow down" branches, the replanning might happen. The robot is deciding whether or not to replan accordingly to various ordered criteria:

- Evolution of the cost of the path (do not change until an “unacceptable” threshold is reached)
- Validity of the path (with respect to local condition but also final goal, taking into account the fact that human will possibly move in a the next seconds)
- Predicted validity of the path based on human behavior

A relatively detailed description of the use of the scheme in a realistic environment (the AIRBUS use case) has been given in Milestone MS32.

Implementation and use

This scheme has been implemented and tested in several conditions. First in WP7 and WP8 integrated with the human-aware navigation planner. Also, the resulting software components have been implemented in ROS in a way to be smoothly integrated in the MoveIt navigation environment. It is also now used and will be extended in the framework of the SPENCER project (social navigation in a dynamic environment like air airport where, from time to time, the environment can be very crowded).

Path Adaptation using Elastic Bands (IOSB)

In shared human-robot workspaces, the robot has to adapt its motion plan during execution, as humans may step or grasp into the robot's path at any time. In order to guarantee human safety, the motion has always to be ensured to be collision-free. Furthermore, the robot's behavior should be intuitively predictable for humans so that they are not scared by an unexpected change of its motion direction. Therefore, the robot should follow a smooth path, and it should adapt the path smoothly to changes in the environment.

A method which can potentially fulfill these requirements is the elastic band framework. It has mostly been applied to mobile robots in a 2D environment, whereas a 10 DoF mobile manipulator in a 3D workspace is considered in the scope of the SAPHARI use cases. The method has to be initialized with a valid path, computed, e.g., by the RRT planner from the ROS *MoveIt!* package. This initial path is then smoothed and adapted to dynamic obstacles observed by the robot's sensors.

The elastic band representation of a path consists of a sequence of so-called bubbles which are robot configurations annotated with a quantification of the free space at these configurations, i.e., the distance to the nearest obstacle. Adjacent bubbles always overlap, so that not only the sequence of configurations, but also the whole connecting path is ensured to be collision-free (see Figure 3). In narrow workspace regions, the bubbles are smaller and thus a greater number of them are required to cover the path.

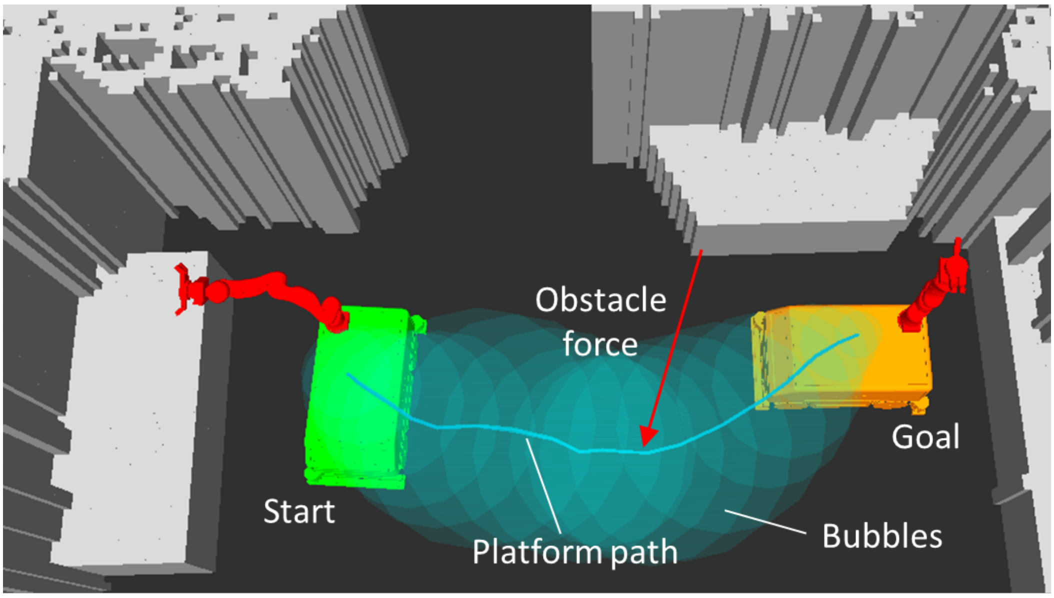

Figure 3: Path adaptation for a mobile manipulator using elastic bands.

Artificial forces are computed which push the elastic band towards a smooth curve and repulse it from obstacles. Internal forces model a mutual attraction of neighboring bubbles in order to smooth and shorten the path. For the computation of external forces, the information of the distance and direction to the nearest obstacle is used. For each joint, the algorithm tests whether a motion in any direction increases the distance to the nearest obstacle and chooses the repulsing force accordingly. In this way, the obstacle information is transferred from the 3D workspace to the 10D configuration space of the robot. It is beneficial to compute the obstacle distances separately for the individual links of the robot, at least for platform and manipulator. Otherwise the motion of the upper manipulator joints has no effect on the computed obstacle distance in many cases, so that no valid force can be obtained.

By applying the artificial forces, the elastic band adapts to moving obstacles detected by the sensors of the robot, resulting in smooth evasive motions, which are intuitively understandable to humans. Figure shows an example in which the mobile manipulator avoids a human crossing its path.

The method has been evaluated in simulations based on real 3D sensor data processed using the octree method from Task 4.1. First results have been published in [Zube2014].

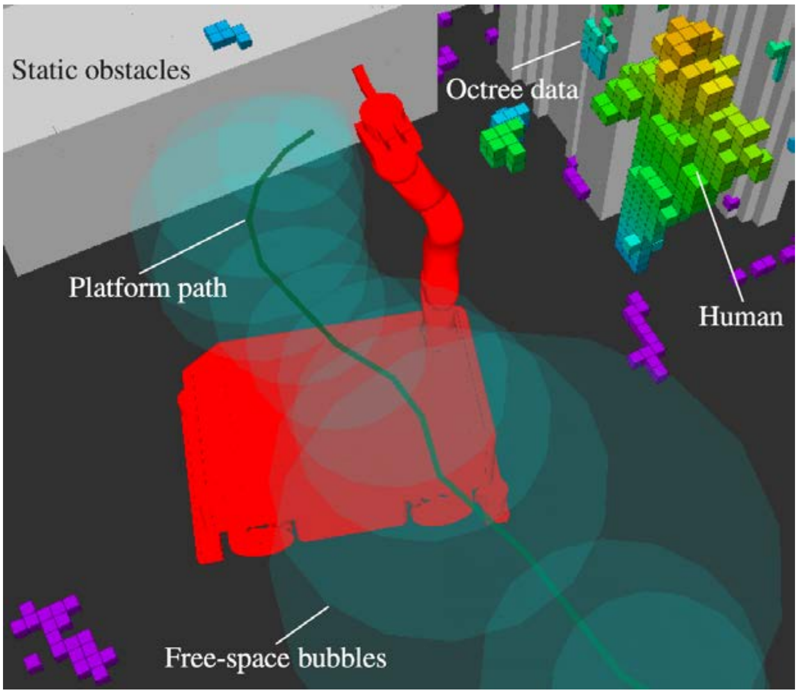

Figure 4: Evasive path of a mobile manipulator computed by the elastic band method.

Conclusion

We have reported here on the methods and scheme we have investigated to tackle the problem of reactively and efficiently adapting robot motion plans in the vicinity of humans and where performing collaborative tasks with them with an essential constraint for a teammate robot: ensure as much as possible without loosing efficiency human safety (of course) but also acceptability and legibility of the robot behavior.

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