HYBRID PLANNING

PICKNIK ROBOTICS

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WELDING WITH THE UR10e

PickNik Robotics is world renowned for the development of MoveIt for ROS as well as executing on world-class robotics products with our partners both terrestrially and in space.

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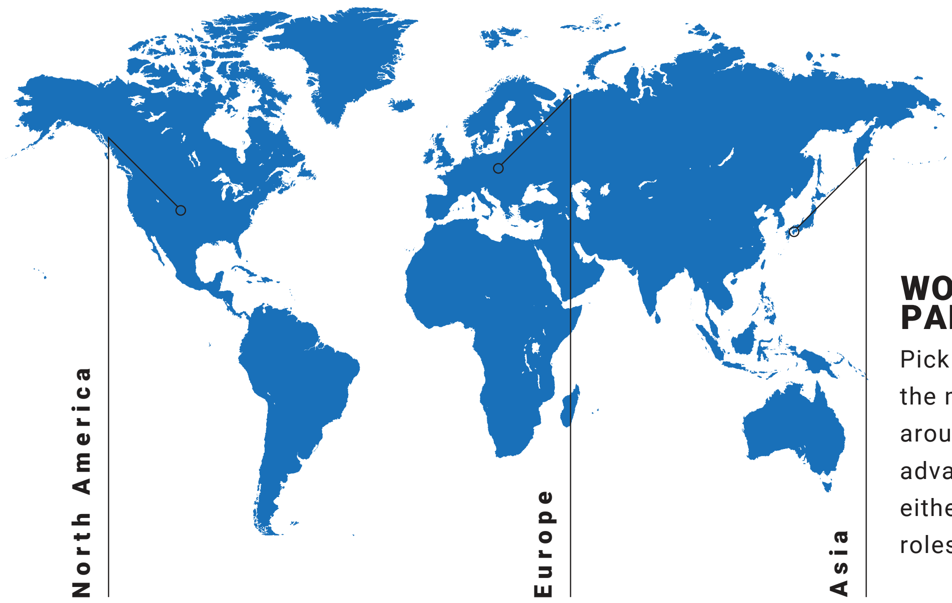

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HYBRID PLANNING - WELDING WITH THE UR10e

ABOUT HYBRID PLANNING

In 2021 the ROS 2 version of MoveIt acquired a novel motion planning architecture. With “Hybrid Planning”finally merged in December, it’s now possible to implement a whole new family of robot applications that require dynamic adaption or updates during trajectory execution. While the architecture is very versatile, the existing default implementations only give a glimpse on what Hybrid Planning is supposed to do in the future. For developers it was still lacking practical examples and design guidelines.

In order to fill this gap, PickNik and Fraunhofer IPA have been working on realizing an industrial robotic welding application using Hybrid Planning. The goal was to streamline the multi-step motion planning approach in an adaptive single-shot execution. This post gives some insights into the design and implementation of the pipeline, as well as our learnings along the way.

ORIGINAL WELDING PIPELINE

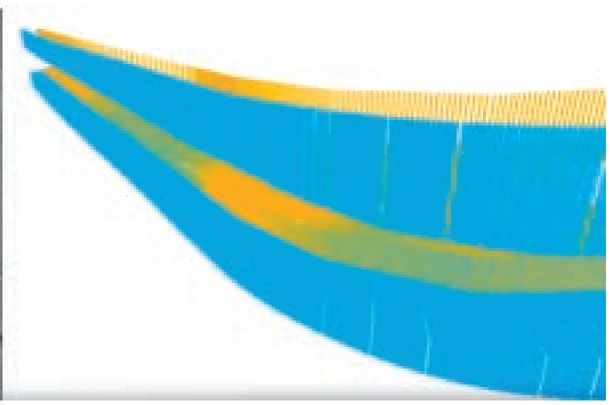
Fraunhofer’s welding robot is a UR10e mounted on a table with a welding gun and a laser scanner attached to the wrist. In the original ROS 1 pipeline, the workpiece is being positioned on the table and has a predefined welding seam that guides the toolpath trajectory. The main difficulty is that the object’s pose is not known with enough accuracy that the very fine tip of the welding gun could be applied in a safe and steady manner. In order to allow for very accurate and robust results, the welding task of the ROS 1 implementation is split into two phases:

1.Scanning Motion:
Trace the predefined welding seam with a laser scanner and generate accurate path waypoints

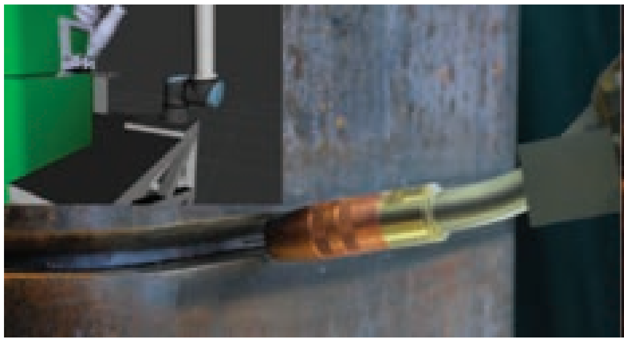
2.Welding Motion:
Follow scanned waypoints with the tip of the welding gun at constant velocity

Before jumping into our Hybrid Planning adaptation, let's take a quick look at these motion phases.

Both phases produce very similar motion plans, only that the scanning motion follows the pre-defined welding seam from a safe distance while pointing the scanner at the seam profile. The images below show the robot during the scanning phase next to a visualization of the scanned sensor data, representing the seam profile.

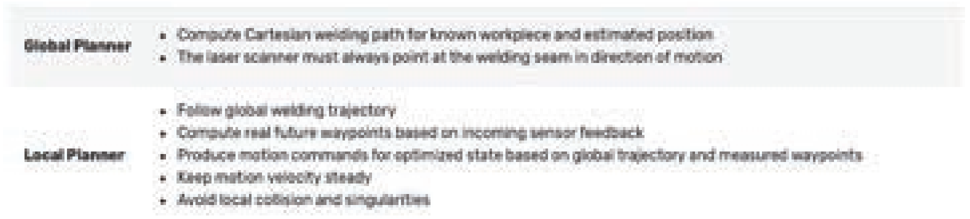


After scanning is completed, the sensor data is processed by iteratively generating Cartesian waypoints and computing a continuous trajectory for the welding gun tip. Below you see the tip being applied at the welding seam which doesn't allow for large error margins. Additionally, in order to produce consistent welding results as depicted on the right, it's absolutely critical that the motion velocity is very stable. This also feeds into the design requirements for the Hybrid Planning setup.



THE HYBRID PLANNING APPROACH

The goal of the Hybrid Planning pipeline was to streamline the welding task by combining the two phases of the original setup into a single run. For that, the scanning task would have to be modified so that it could be run online while already applying the welding gun. The general design requirements of the global and local planners come quite naturally when separating static and dynamic constraints of the task:

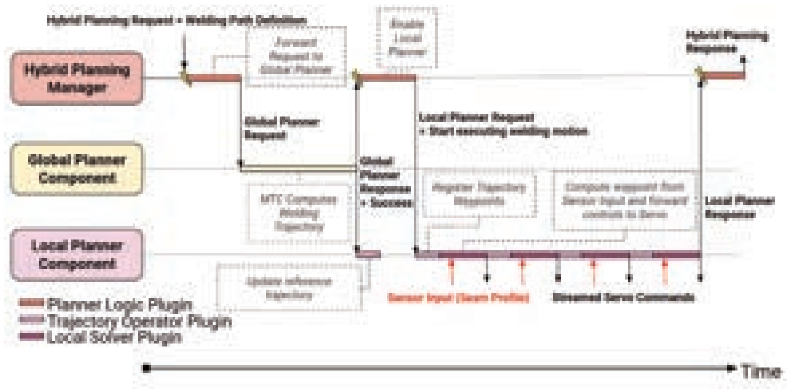


Global Planner	• Compute Cartesian welding path for known workpiece and estimated position • The laser scanner must always point at the welding seam in direction of motion
Local Planner	• Follow global welding trajectory • Compute real future waypoints based on incoming sensor feedback • Produce motion commands for optimized state based on global trajectory and measured waypoints • Keep motion velocity steady • Avoid local collision and singularities

The listed planner requirements don't cover all of the problems that need to be solved for the whole application. For instance, approaching the seam in a safe way, running the first bits of the welding path where sensor input might be missing and good error handling would involve more sophisticated requirements that are not considered here.

RUNTIME LOGIC

With the planner requirements specified, we draft a minimal runtime logic that defines the sequence of communication and work that the planners should run. The logic shows how first the global planner is requested to produce a global welding trajectory, which is then forwarded to the local planner. The local planner is then enabled for trajectory execution, which effectively almost resembles a closed-loop control pattern: 1. read sensor input, 2. compute waypoint, 3. publish a new control command. When the trajectory has been completed, the local planner terminates and returns the successful action result. There aren't a lot of implementation details included here, but the drawing should already give an idea on how the pipeline is supposed to work in practice.


Hybrid Planning Request + Welding Path Definition
Forward Request to Global Planner
Enable Local Planner
Hybrid Planning Response
Hybrid Planning Manager
Global Planner Request
Local Planner Request + Start executing welding motion
Global Planner Component
Global Planner Response + Success
MTC Computes Welding Trajectory
Register Trajectory Waypoints
Compute waypoint from Sensor Input and forward controls to Servo
Local Planner Response
Local Planner Component
Update reference trajectory
Sensor Input (Seam Profile)
Streamed Servo Commands
Planner Logic Plugin
Trajectory Operator Plugin
Local Solver Plugin
Time

DEMO IMPLEMENTATION

The setup and source code of the demo can be found in the repo UR10e_welding_demo. It includes the ported launch and configuration packages for bringing up the UR10e robot, both for simulation and hardware runtime. The hybrid_planning_demo package includes the planner implementation, in particular the main node executable which initializes the planning requests and the implementations for the global and local planner plugin interfaces.

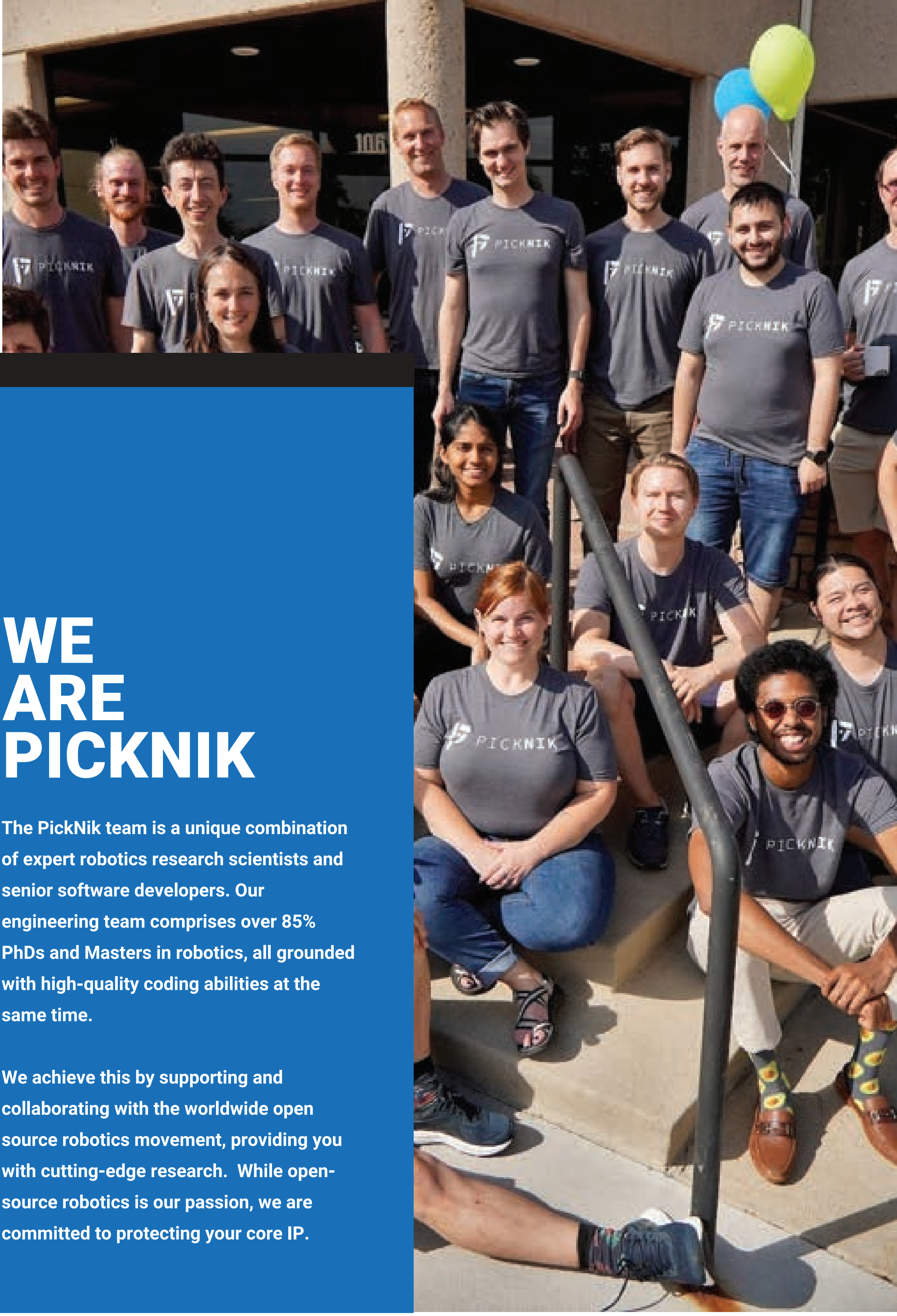
The solver of the global planner is implemented by the class GlobalMTCPlannerComponent which, as the name indicates, handles the planning requests with a custom MoveIt Task Constructor (MTC) task implementation.

At the time of writing this blog post, the MTC task merely contains a couple stages that handle Cartesian trajectories for approaching, welding, and retreating from the workpiece, as well as a simple trajectory processing step. This task implementation will be replaced with a modified version of the original MTC task from the ROS 1 pipeline once the port of the corresponding library is completed. For now, this task fully serves as a test case for the global trajectory execution which allows us to focus more on the local planner.The local planner includes two plugin implementations, namely the SimpleServoSampler for the TrajectoryOperatorInterface and the ServoSolver for the LocalConstraintSolverInterface. Which seems complicated at first but makes more sense when looking at the purpose of these plugins. The SimpleServoSampler is the trajectory operator that handles the registration and unwinding of the global reference trajectory. The plugin basically provides the immediately upcoming reference waypoints - or local trajectory - that are supposed to be followed. The ServoSolver plugin, implementing the LocalConstraintSolverInterface, uses iterative local trajectories as target and computes the commands to follow them based on the current robot state. Additionally, the plugin has a subscriber to a TwistStamped message topic that resembles the corrective motion commands that are expected for sensor-based adaptations. In the demo, the twist message can be published using keyboard inputs which will result in modified end-effector rotations. This example shows how the hybrid planning pipeline supports reacting to sensor input while still following the constraints of a global trajectory.

LEARNINGS & TIPS

The Hybrid Planning pipeline uses a completely new architecture that requires a lot of thinking ahead and planning in order to produce the desired results. Discussing, simplifying and designing the requirements for the different plugins before starting any of the implementation helps a lot with this. Also, drawing of the runtime logic acts as a mental model that aids with understanding the behavior of the system. We decided to at first start with a very minimalistic implementation that just runs a simple trajectory before iteratively adding more features and improvements. The architecture makes it easy to focus on changing one thing at a time, and that’s probably a best practice that everyone should follow when working with it.

As of now, there is only a very simple set of plugin implementations provided with the hybrid planning package, but as seen here, it often makes a lot of sense to implement custom solvers. The MTC task that we use in the demo is probably not very useful for other settings, just like a sensor-based waypoint adaptation class is probably very specific to its application and context. Because of that it won’t be very easy to provide a feature-rich set of generic hybrid planning solvers that everyone can use for their application just like that. More likely we would continue to build and publish more reference implementations and examples that can be taken as recipes for solving certain types of problems. We hope that at some point there will be a recipe for any class of dynamic motion planning problems where developers can start from instead of building the pipeline from scratch. We are still investigating use cases and have active projects around shaping the ideas and best practices around hybrid planning.



WE ARE PICKNIK

The PickNik team is a unique combination of expert robotics research scientists and senior software developers. Our engineering team comprises over 85% PhDs and Masters in robotics, all grounded with high-quality coding abilities at the same time.

We achieve this by supporting and collaborating with the worldwide open source robotics movement, providing you with cutting-edge research. While open-source robotics is our passion, we are committed to protecting your core IP.

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