Hard Material Small-Batch Industrial Machining Robot

HEPHESTOS Project

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European Robotics Forum

WP 3 Software Services for Planning and Programming

Geir Hovland & Ilya Tyapin, UiA

Stefan Anton, Easy-Rob

PLANNING AND PROGRAMMING MODULE (1)

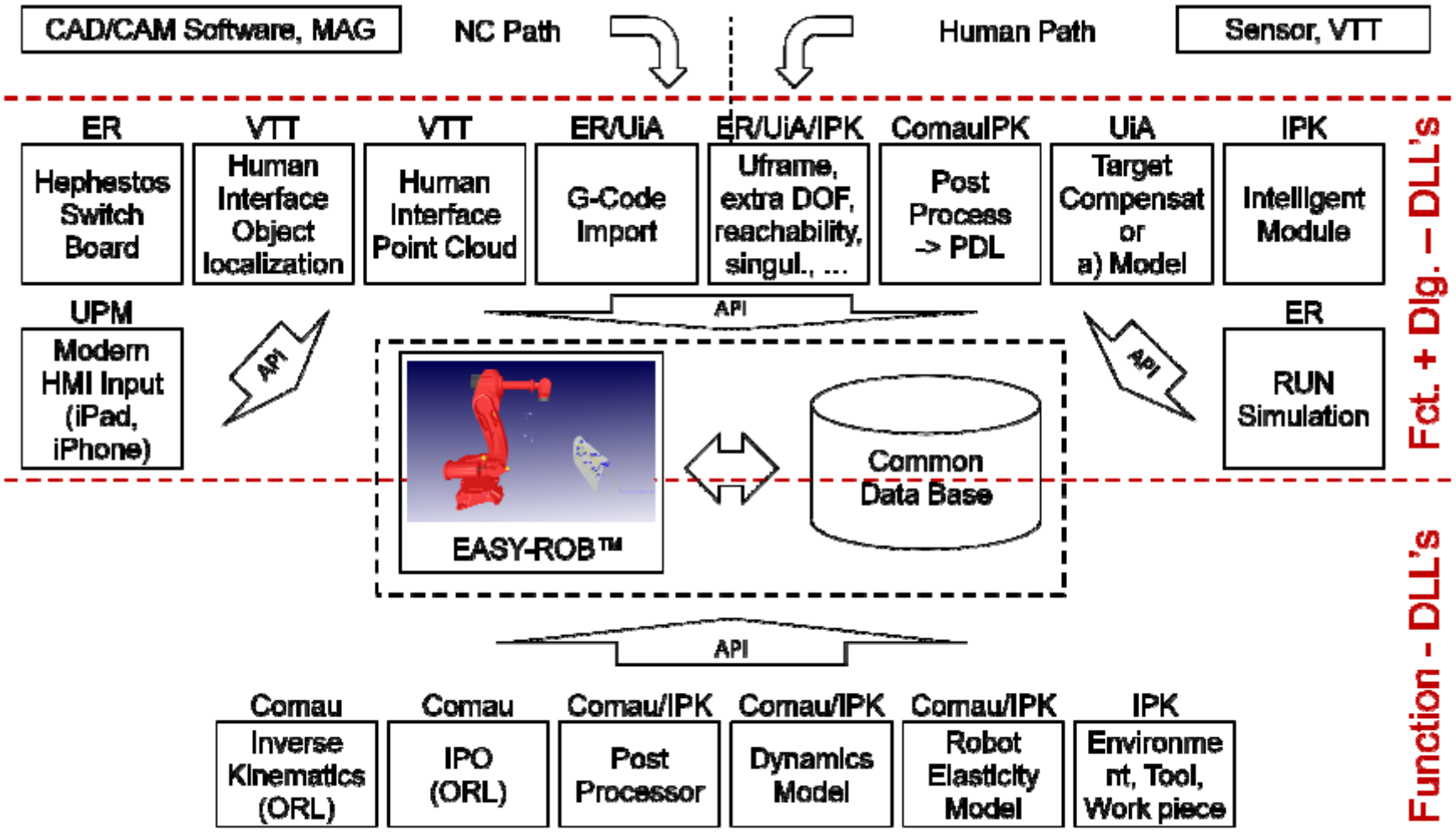


Figure 24: HEPHESTO planning and programming functional architecture.

PLANNING AND PROGRAMMING MODULE (2)

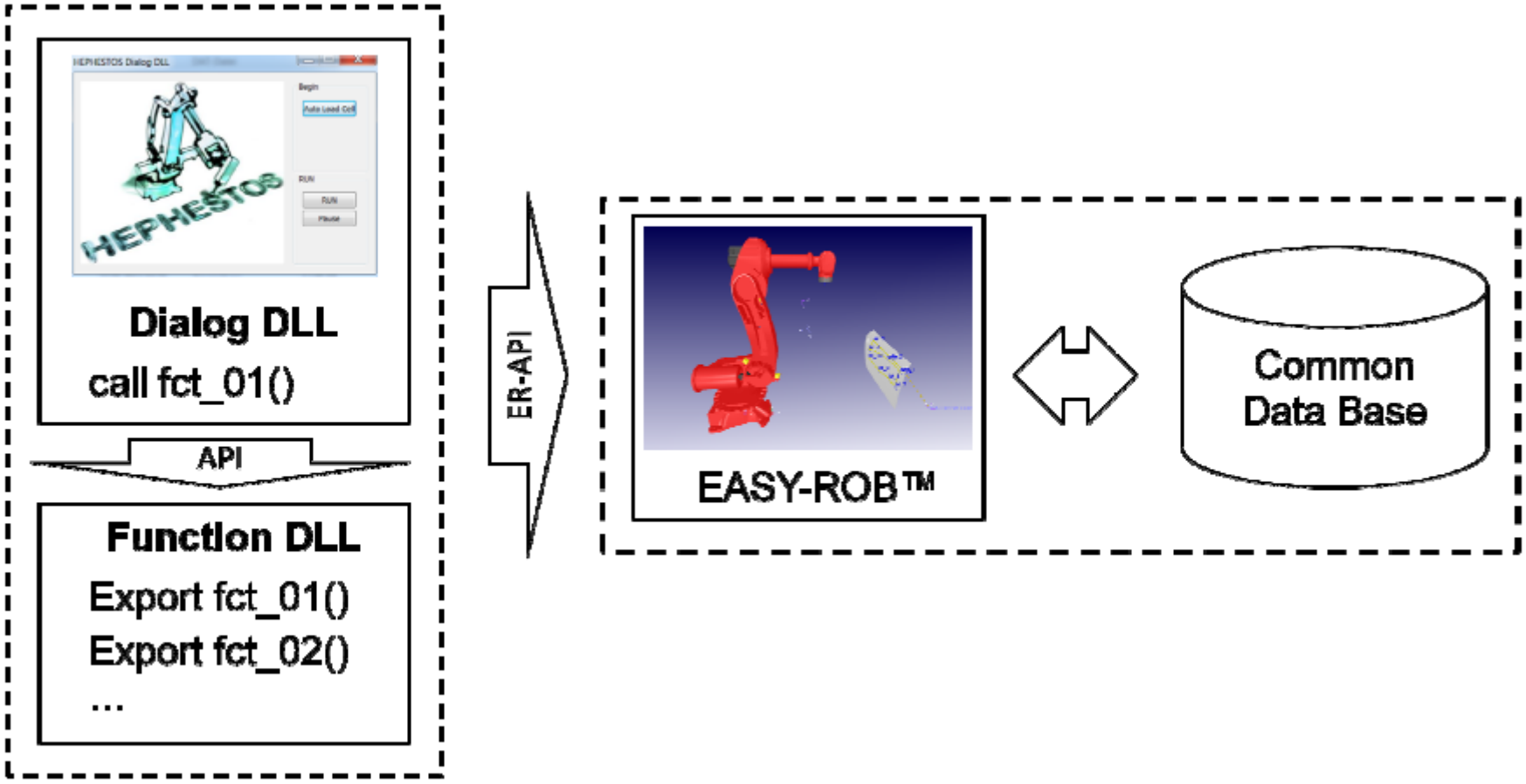


Figure 22: Easy-Rob Open Programming Environment Interfaces

PLANNING AND PROGRAMMING MODULE (3)

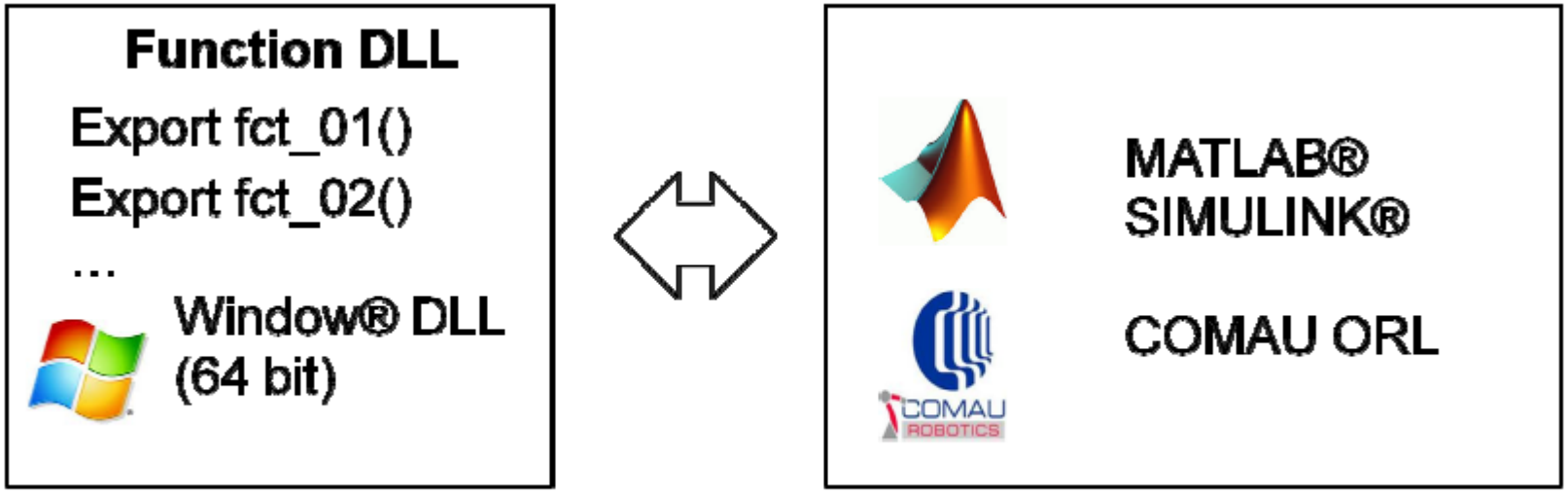
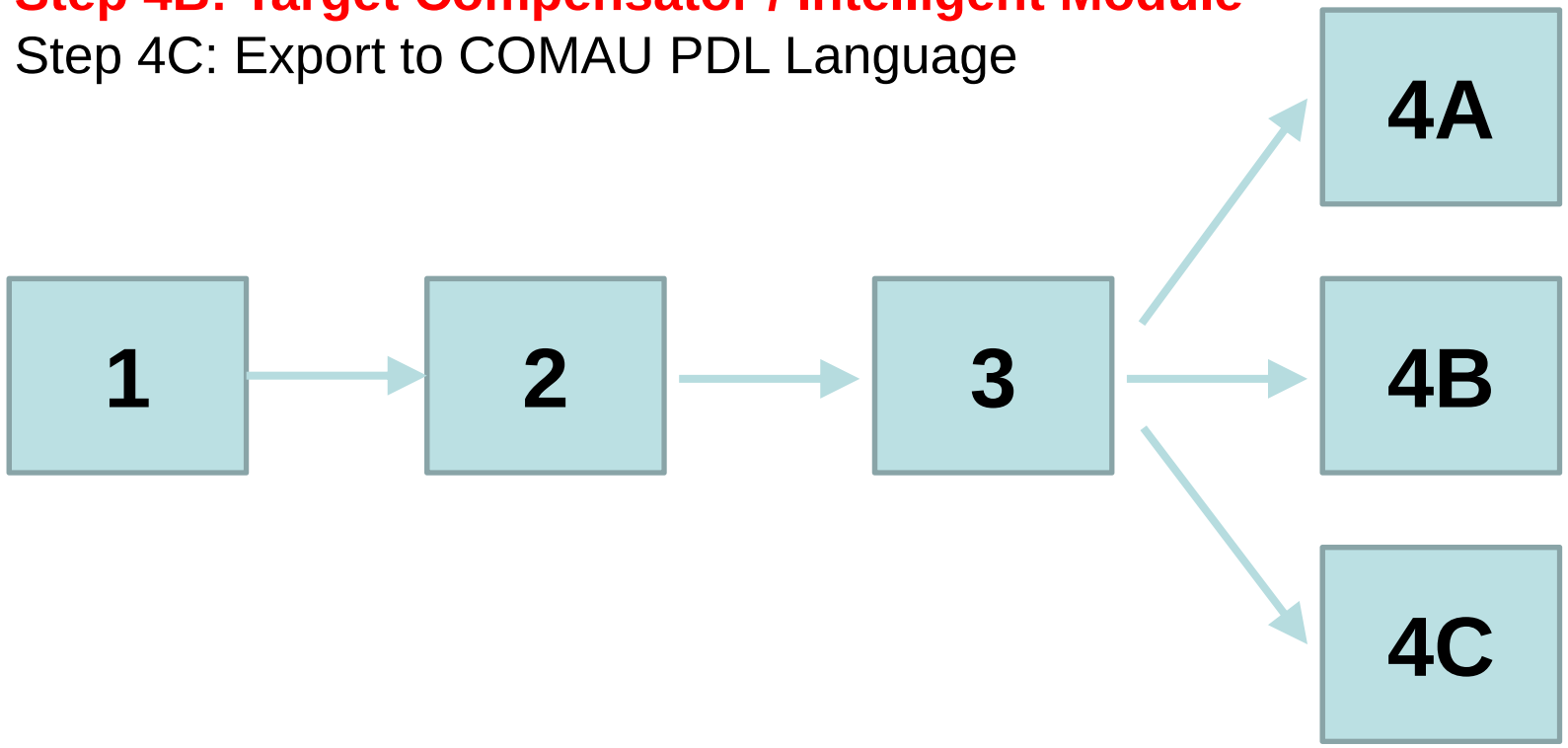


Figure 23: Easy-Rob – Matlab engine communication interface

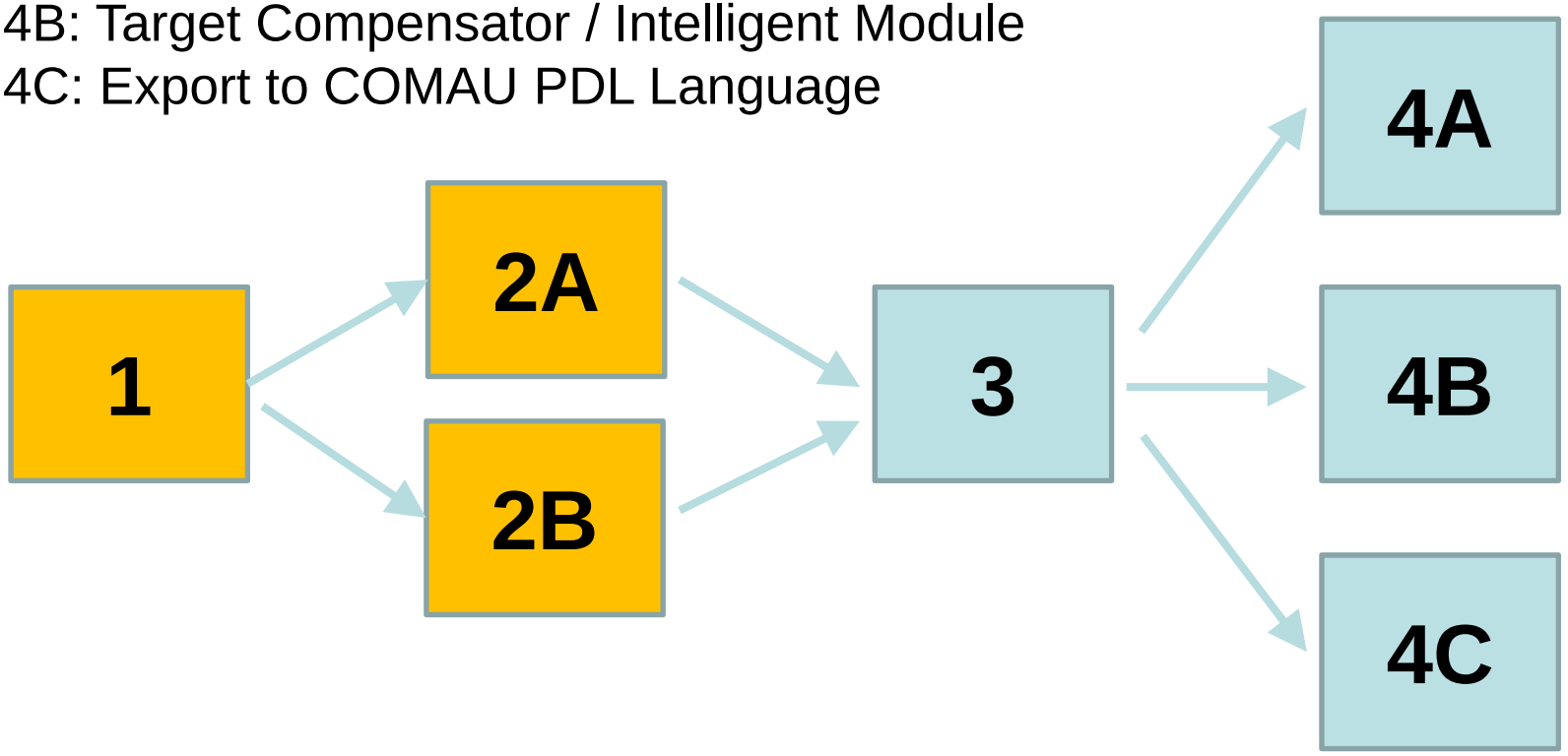
WORKFLOW FOR NC-PATH SCENARIO

- Step 1: NC-Path Generated by CAD/CAM Software (G-code or APT-CL)
- Step 2: Imported and Visualized in Easy-Rob
- Step 3: User Frame, Extra DOF, Reachability
- Step 4A: 3D Simulation
- **Step 4B: Target Compensator / Intelligent Module**
- Step 4C: Export to COMAU PDL Language



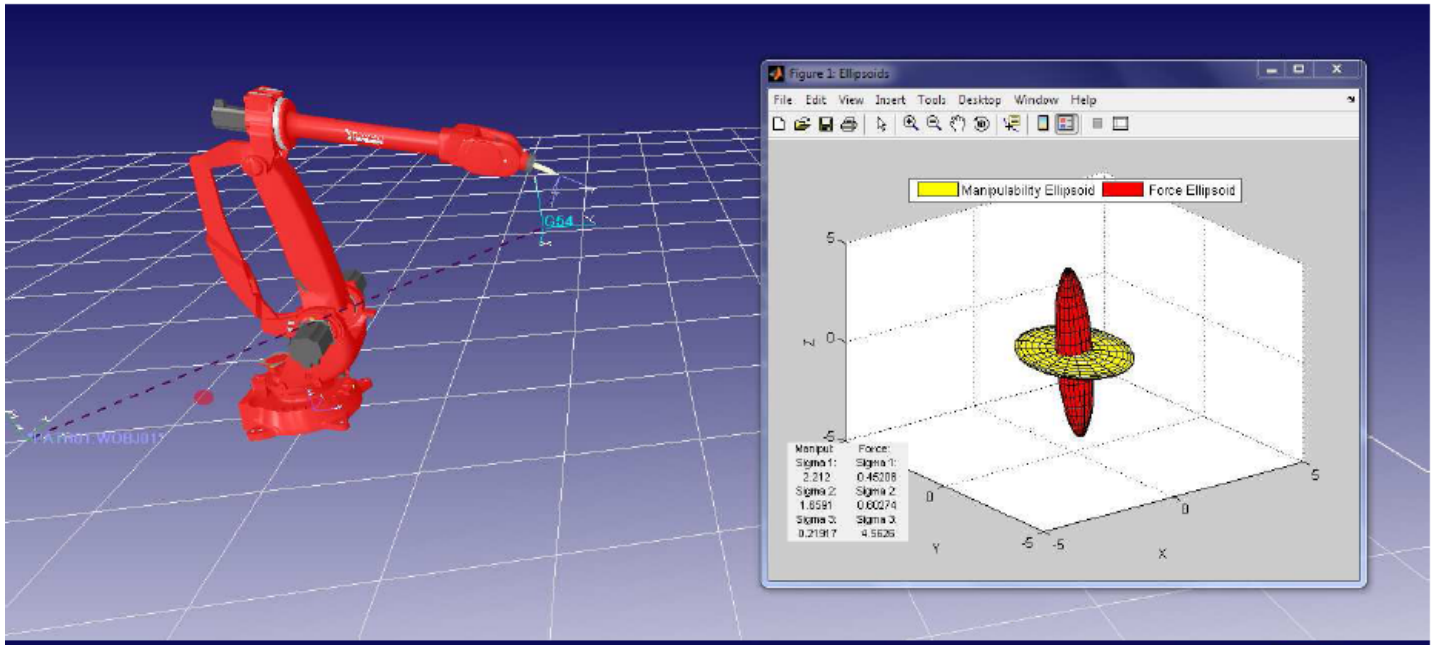
WORKFLOW FOR HUMAN/SENSOR PATH SCENARIO

- **Step 1: Path Created Using Sensor Device.**
- **Step 2A: Human Interface Point Cloud in Easy-Rob.**
  Conversion of Cloud to Robot Targets (difference with nominal)
- **Step 2B: Human Interface to Robot Targets**
- Step 3: User Frame, Extra DOF, Reachability
- Step 4A: 3D Simulation
- Step 4B: Target Compensator / Intelligent Module
- Step 4C: Export to COMAU PDL Language



INTELLIGENT MOTION PLANNING AND PROGRAMMING FUNCTIONS
Dynamic Robot Reconfiguration

- Algorithms for Robot's 6th DOF + Turntable (7th axis)
- Considering Interpolated Robot Motion
- Considering Quasi-Static Loads (Force Ellipsoids)
- Robot Dynamics and Control System Performance
- MATLAB-Interface with Easy-Rob



- Paper Submitted to AIM 2014 (France)

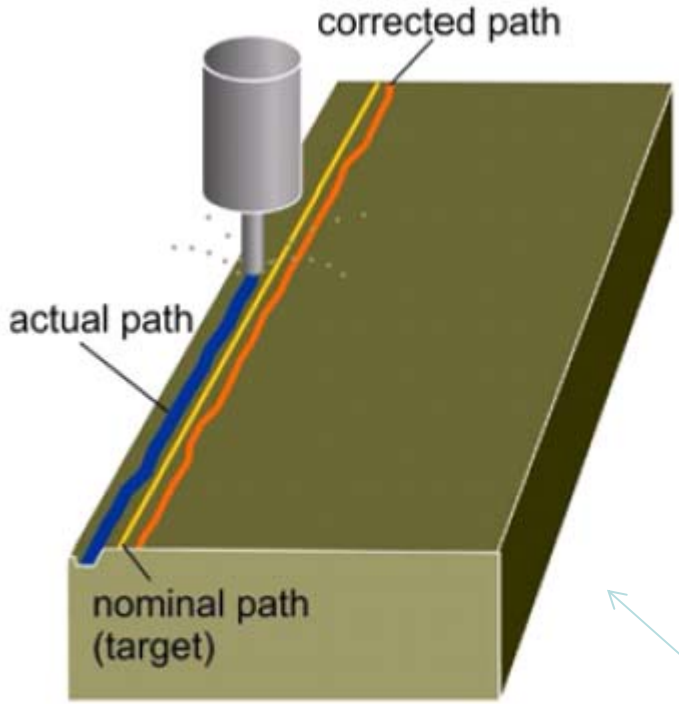


Fig. 1. *Illustration of stiffness-based path correction for a machining operation. Picture courtesy of Fraunhofer IPK.*

Fig. 3. *Reflector position used when estimating stiffness of joint 1.*

Goal: Create a DLL in Hephestos which can do this.

- Combined stiffness: Bearings, Gears, Arms, Controller

Fig. 4. *Reflector position used when estimating stiffness of joint 2.*

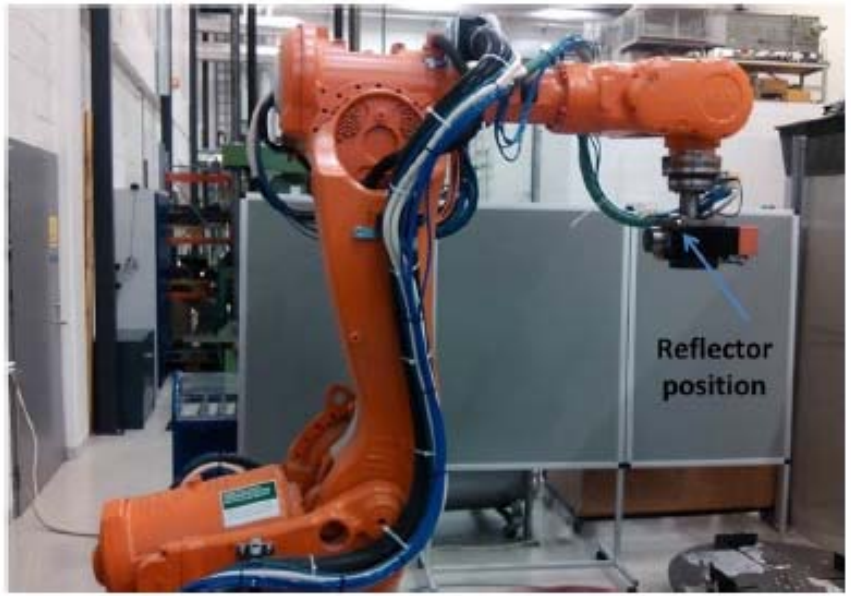


Fig. 5. *Reflector position used when estimating stiffness of joints 3-6.*

Joint Stiffness Identification

Identification Results

Joint #	1	2	3	4	5	6
K,(relative)	1.00	0.918	0.858	0.049	0.021	0.051

TABLE IV. *Identified combined joint stiffnesses.*

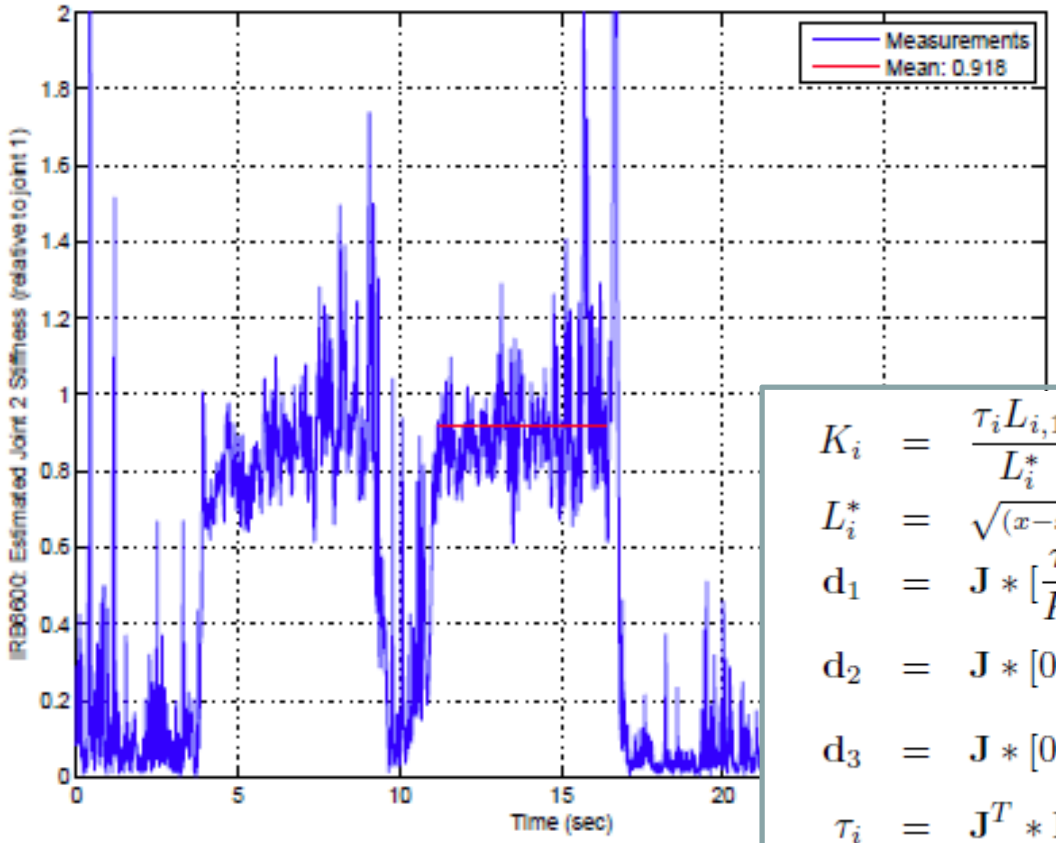


Fig. 7. *Estimated stiffness of joint 2.*

$$
\begin{aligned}
K_i &= \frac{\tau_i L_{i,1}}{L_i^*} \\
L_i^* &= \sqrt{(x-x_0-d_{J,x})^2+(y-y_0-d_{J,y})^2+(z-z_0-d_{J,z})^2} \\
\mathbf{d}_1 &= \mathbf{J} * [\frac{\tau_1}{K_1}\ 0\ 0\ 0\ 0\ 0]^T \\
\mathbf{d}_2 &= \mathbf{J} * [0\ \frac{\tau_2}{K_2}\ 0\ 0\ 0\ 0]^T \\
\mathbf{d}_3 &= \mathbf{J} * [0\ \frac{\tau_2}{K_2}\ \frac{\tau_3}{K_3}\ 0\ 0\ 0]^T \\
\tau_i &= \mathbf{J}^T * \mathbf{F}
\end{aligned}
$$

- Document the milling results and measurements performed in Oulu, Grimstad and Berlin
- Submit a paper on this topic to MESA 2014
- Start working on the Easy-Rob DLL

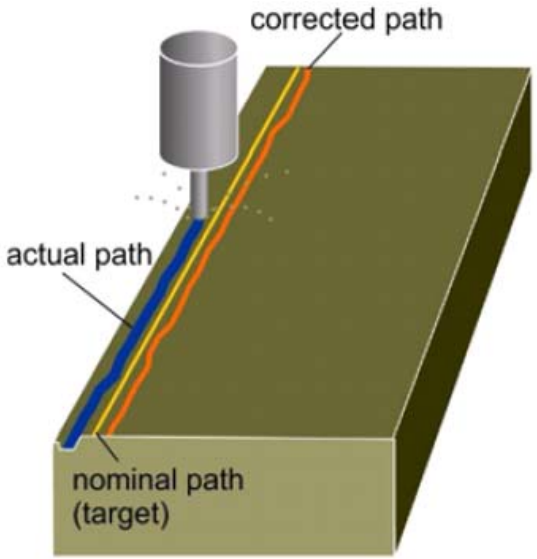


Fig. 1. *Illustration of stiffness-based path correction for a machining operation. Picture courtesy of Fraunhofer IPK.*

Figure 19: Experimental Setup: FARO Laser Tracker and ABB 6660.