ERF2014 WORKSHOP

Advances in robot machining

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Advanced Control Techniques for Robotic Machining

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EU initiatives –robotic machining

COMET

- “right first time machining”
- High –end milling
- Precision and quality through positioning
- High-tech (costs) sensory techniques
- Full automation
- Proprietary technology
- Mass production

HEPHESTOS

- multi-steps iterative methodology
- Combination of processes (milling, grinding, polishing, drilling, tapping etc.)
- Precision and quality through force-feed control
- Affordable sensing technology
- Human-in-loop
- Open frameworks
- Low-batch high-variants manufacturing

Some common points in planning and programming – background for established cooperation

Industrial Robot Control Systems – Machining Operations (SOTA)

- Not a development goal (position and trajectory tracking control primarily, niche developments)
- Compensation control (payload, feed-forward dynamic control)
- Interaction control (extra package – additional force control , general purpose, impedance control KUKA LWR)
- Trends for machining (CNC robot control , “If automotive companies apply robots for machining, we will do something”)

Specific control improvements are for machining applications are urgently needed

Improved Robot Control – Machining Operations - I

Position Control Improvements

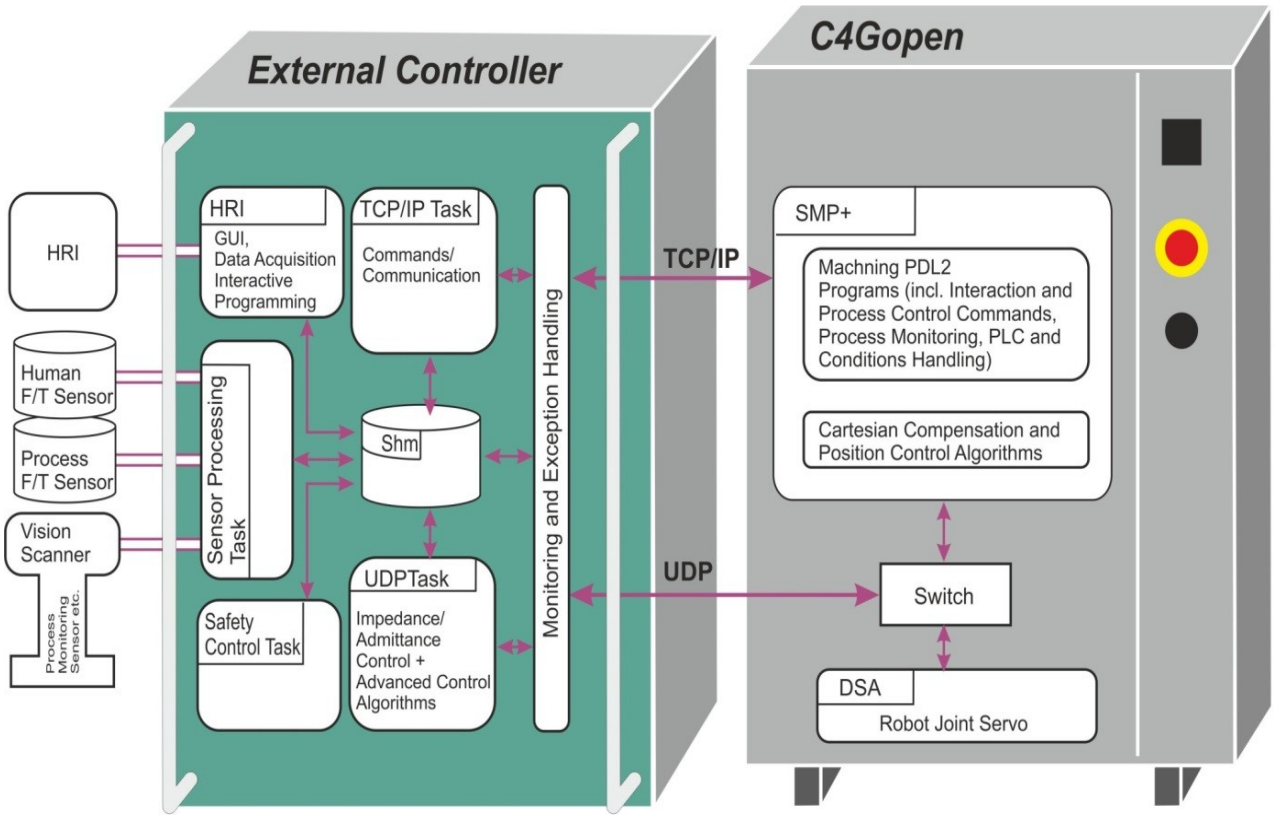
- Ripple suppression
- Trajectory shaping
- **Joint elasticity** control and compensation (gears!)
- Compensation control (cutting forces)
- Compensation for joint change of direction (backlash, friction)
- Override control (real time adaptation)
- Increased stiffness of the controller

Improved Robot Control – Machining Operations -II

Contact-task , force- and impedance based Control

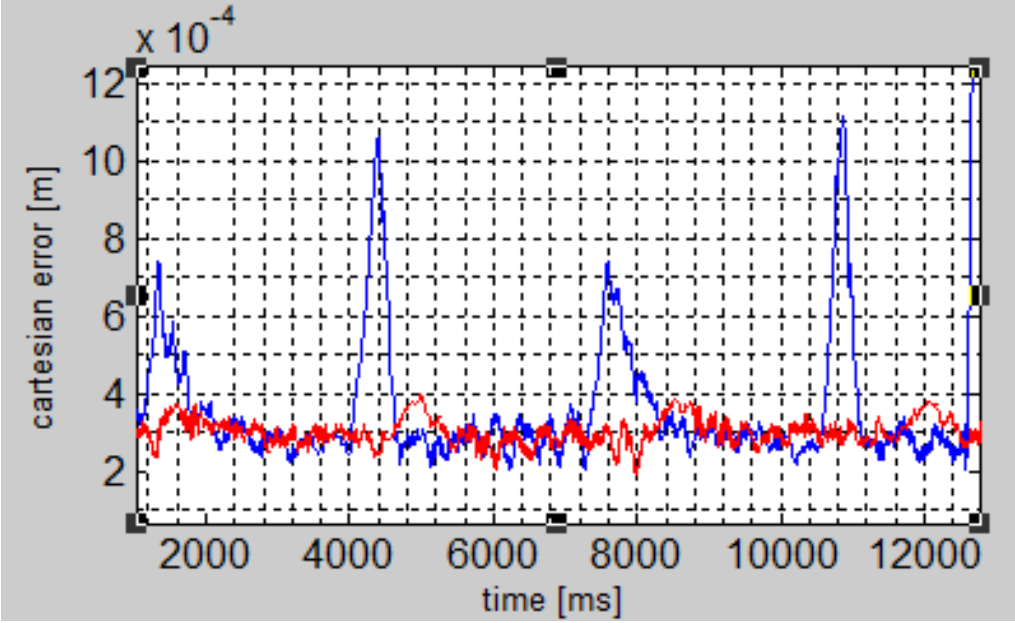
- Position based impedance and force control
- Impedance control (milling – robot configuration and direction compensation)
- Orthogonal force-feed control (grinding, polishing)
- Collinear force-feed control (milling)
- Feedback robot dynamic and cutting force disturbances compensation (“computed torque”, “resolved acceleration”, “non-linear decoupling”….- based interaction control)
- Human-robot interaction control (manual guidance, admittance-display, adaptive contact transition control)

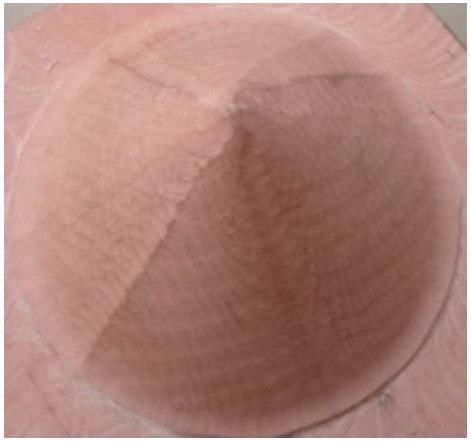
Integration Environment C4GOpen

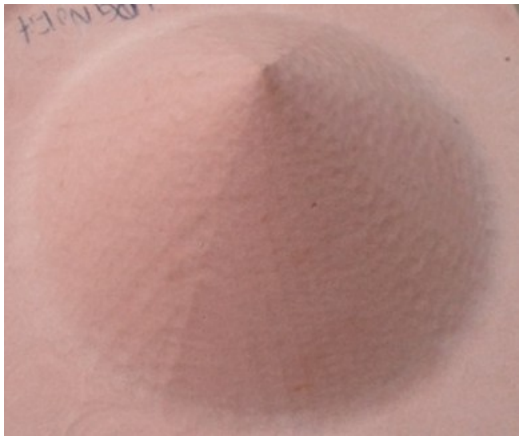


Preliminary developments (FP6 ARFLEX, ECHORD RODIN), running activities (FP7 X-Act, FP7 IP ROBO-PARTNER), COMAU developments (C5GOpen)

Position control – path governor (backlash, friction compenstion)







Hard metal (inconel) and novel tools (ceramic-based, PCD)

- New ceramic tools
- High speed (> 30000 rpm, 0.15 m/s) - power
- High temperatures (1500 C)
- Chip formation

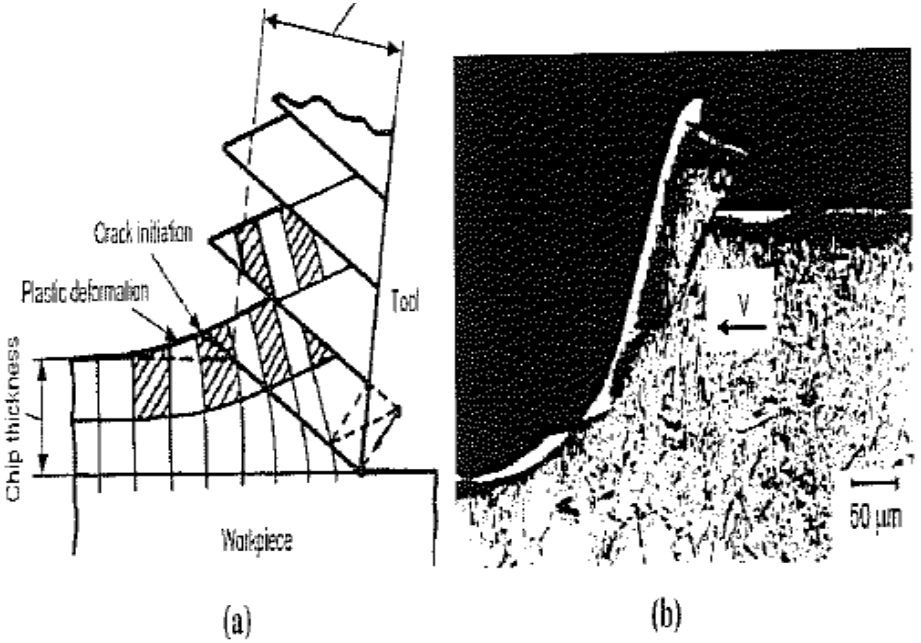
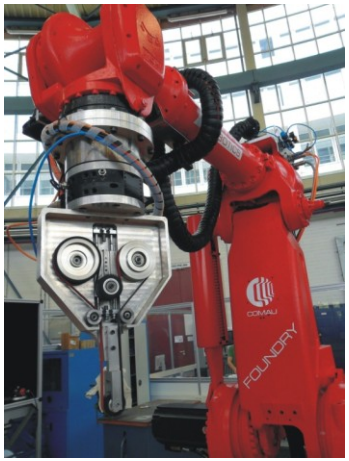
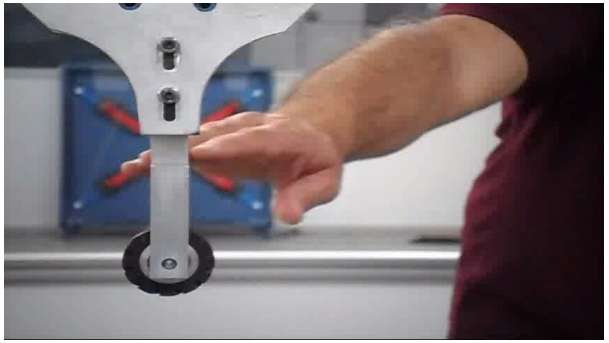
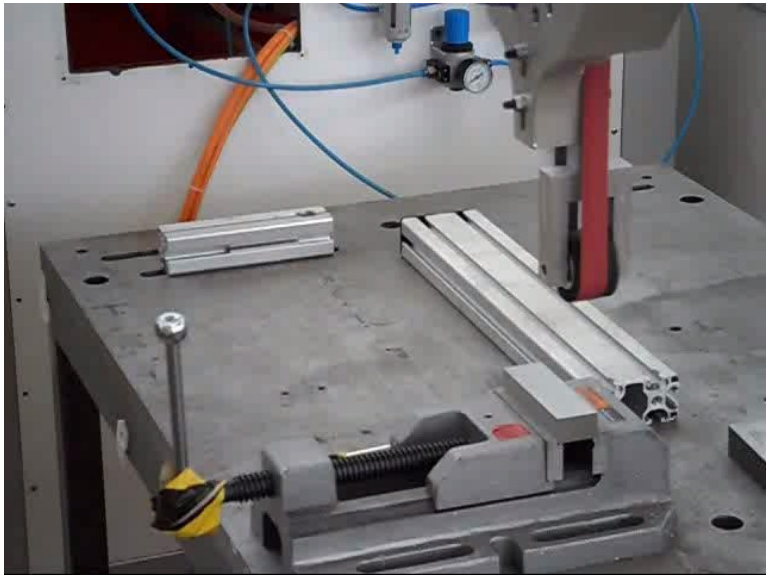


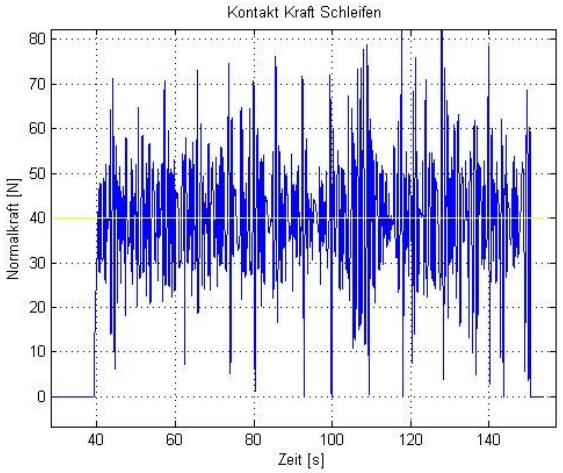
Figure 1.4 (a) Model of chip formation suggested by Nakayama *et al.*, and (b) its experimental verification by König *et al.* [11]

Hard metal – Robotic Grinding– Initial experiments









Very good removal rates (new tools)

Feasible Feed-force control (further investigations)

High frequent oscillations

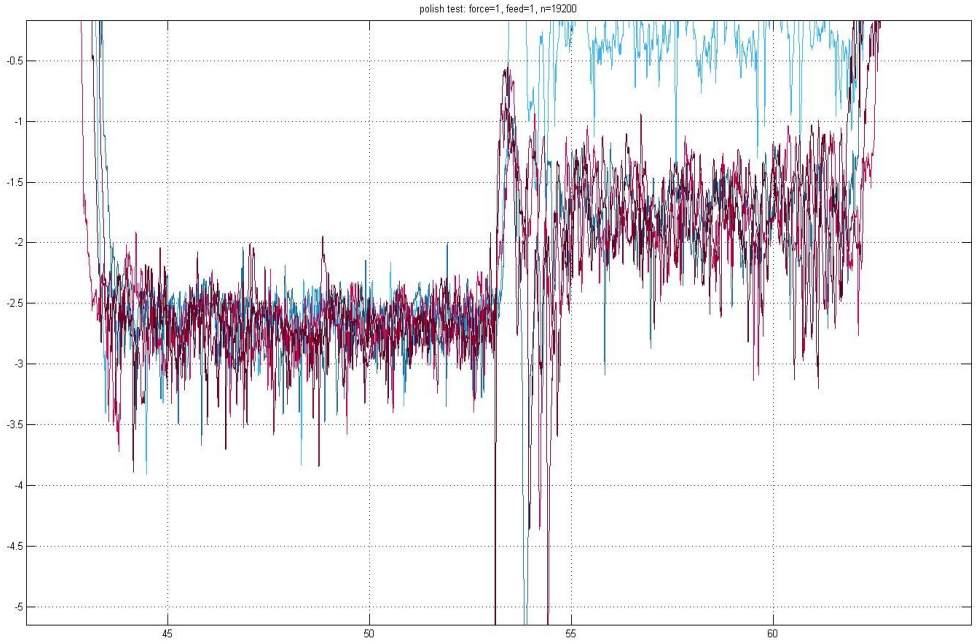
Force/impedance control – initial experiments – polishing

Force tracking : 1.5 N

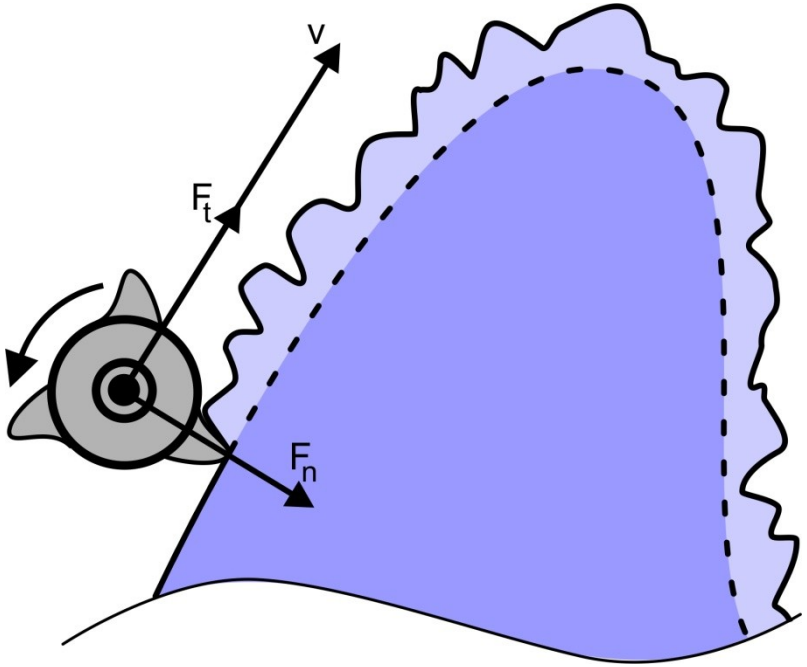
Good achieved performance:

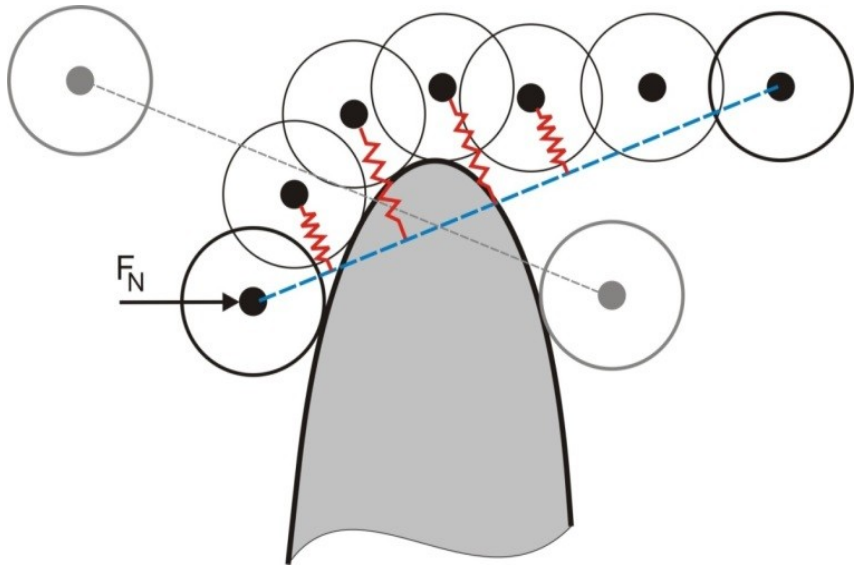
Feed tracking : 5, 10, 20 mm/s
Force control : 1.5, 3, 5 N
Easy Programming, Reproducibility

Relatively good surface quality (Ra < 0.4 μm)
(precise motion in robot “dark motion zone”)



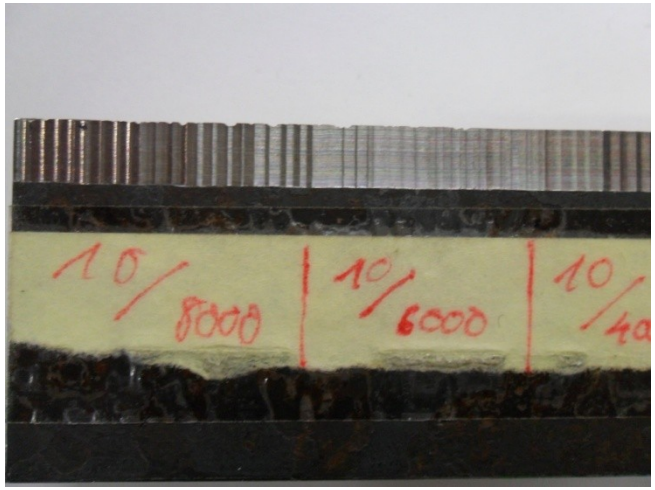
Co-directional feed/force and force/impedance control algorithms

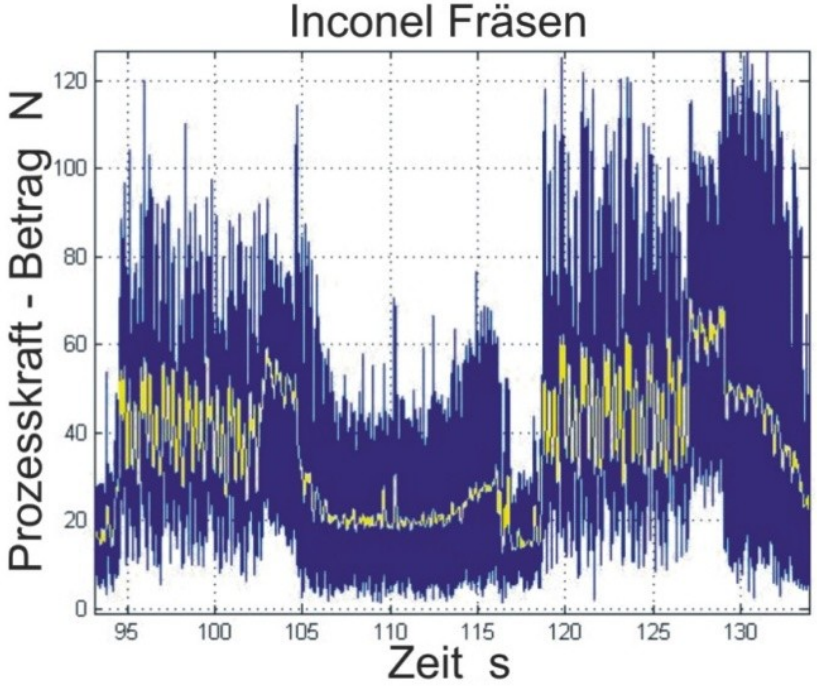




Manual programming

Hard metal – Robotic End Milling – Initial experiments





Feasible metal removal rates

Critical chattering – errors higher than registered robot control errors

Relatively low forces (high frequent oscillations)

Ceramic tools prototypes – Stainless Steel

Ceramic tools experiments– Inconel

Instead of Conclusion

Advanced robot control for machining - Perspectives

- Good potential to cope with robot machining problems and achieve goals
- Combination of milling (material removal), grinding and polishing (quality) operation needed to make final products
- Relevance of further development of tools and adaptation of control techniques
- Extensive use of modeling and model based control
- Experimental investigations (understanding of robot and control performance) and benchmarking are quite important
- Good perspectives also for “robotic hard” materials