

Robot Accuracy: Online Compensation (EU COMET Project)

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ABSTRACT

The 30 month COMET project aims to overcome the challenges facing European manufacturing industries by developing innovative machining systems that are flexible, reliable and predictable with an average of 30% cost efficiency savings in comparison to machine tools. From a conceptual point of view, industrial robot technology could provide an excellent base for machining being both flexible and cost efficient. However, industrial robots lack absolute positioning accuracy, are unable to reject disturbances in terms of process forces and lack reliable programming and simulation tools to ensure right first time machining, once production commences. These three critical limitations currently prevent the use of robots in typical machining applications. The COMET project is co-funded by the European Commission as part of the European Economic Recovery Plan (EERP) adopted in 2008. The EERP proposes the launch of Public-Private Partnerships (PPP) in three sectors, one of them being Factories of the Future (FoF). Factories of the Future is a EUR 1.2 billion program in which the European Commission and industry are collaborating in research to support the development and innovation of new enabling technologies for the EU manufacturing sector. The 14 project partners combine their experience and expertise in manufacturing from 8 countries across Europe to use plug-and-produce COmponents and METHods for adaptive control of industrial robots enabling high-end machining for cost effective, flexible and reliable manufacturing solutions.

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INTRODUCTION

The objectives from COMET [1] were:-

- Pioneer a new generation of adaptive production systems using industrial robots
- Demonstrate the new technologies in industrial environments in these four sectors:
 - *automotive*
 - *aerospace and aeronautics*
 - *moulds and die*
 - *high precision components*
- Disseminate project results and develop training programs

This paper is focused on the dissemination of results.



Figure 1. COMET Partners

ONLINE COMPENSATION

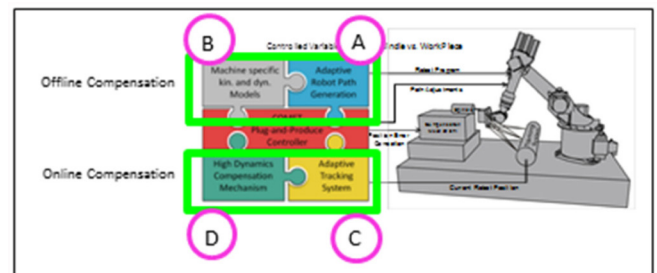


Figure 2. Project Structure

Two methods of Online compensation were made using a metrology system. The first method was to give real-time feedback to the robot - to improve the robot accuracy in its environment. This was called "Configuration C" (shown in Figure 2)

The second method used the same metrology system but coupled to both robot and a high dynamic compensation mechanism to further improve machining accuracy. This was called "Configuration D".

Metrology System

A solid state camera system was used from Nikon Metrology. It measures strobed IR LED's at frequencies up to 1kHz (High Frequency "HF" control) with latency $\approx 3\text{ms}$, using linear CCD's and sub-pixel interpolation. As part of its manufacture the camera has a calibration grid created. This is by having LEDs on a very large Coordinate Measuring Machine running through its full working volume. In operation if a LED is introduced into its field of view it measures it as a coordinate. With three or more LEDs a 6D Frame is measured.

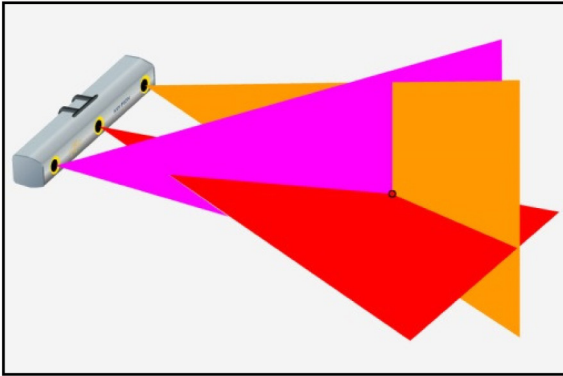


Figure 3. Coordinate tracking (single LED)

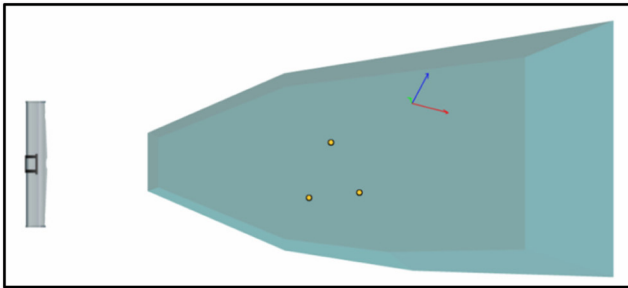


Figure 4. Frame tracking (three or more LEDs)

Multiple frames can be tracked simultaneously, allowing many measurement opportunities including relative motion tracking and nested tracking. This is ideal for robotics - as they are programmed with two coordinate reference systems (tool and base)

Nikon Metrology has a commercial solution for online compensation called Adaptive Robot Control (ARC), where in a quasi-static deployment the robot is guided to a position independent of any robot errors. This correction is applied at the "user level". By that we mean the coordinates programmed off-line and as seen as target points on the robot controller. For path following applications a dry-run/wet-run approach is made, where the path is corrected after the dry-run - but only monitored during wet-run. This has the benefit of not correcting against the flow of the path (which can introduce extra backlash errors). This works because a robot is repeatable.

However it drifts over time, so the camera cannot be removed from the cell (so the monitoring is a warning limit to repeat another dry-run). Applications such as robotic trimming are ideal for this as the robot programs are relatively light/small. The tolerances are usually beyond off-line compensation - but within the mechanical capabilities of the robot (typically $0.5\text{--}0.75\text{mm}$ are normal specifications). In fact the programming methodology is developed to minimise the number of points. On COMET the focus was on detailed machining, and the CAM partner (Delcam) has developed a robotic offline programming solution with its origins on CNC machining (PowerMill) with very large program sizes. The goal here was not to use dry runs, as much as anything because of the sheer volume of data correction handling on each point.

Configuration "C" Online Robot Compensation

Lund University in Sweden was the key partner in this work package. The application conundrum to solve in these applications is

- The robot knows where it is (but not to high precision)
- The metrology system knows where the robot is (to high precision)
- The robot is planning its next move, based on where it thinks it is - and where it wants to go (with all its kinematic/compliance/backlash sources of error)
- The metrology system doesn't know where the robot is going to next (very quickly)
- So how do you apply a correction?

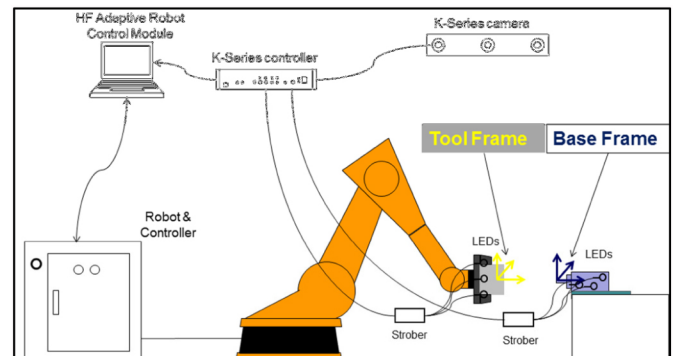


Figure 5. Configuration "C" set-up

The robot is also programmed at a high level - on this project based on 3D CAD coordinates. This is used in the robot controller to calculate its forward motion. The first part of the calculation is called "inverse kinematics" where the robot mathematically knows where it needs to go (target) which is a 6D frame, with respect to a jig /part 6D frame (base). And it knows where it starts from. Using its kinematic model and the 6D frame on the robot tool it's calculates how to move to the target. From fundamental (can it reach?) to which direction to rotate its joints to get to the target.