

Robot Accuracy: Offline 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

OFFLINE COMPENSATION

The COMET process is defined in Fig. 2. Starting with 3D CAD, there is a path to machine (shown in orange). This is performed by a tool of a certain geometry/diameter so the robot is assigned a path offset from the product (shown in red). In reality the robot performs a different path (green).

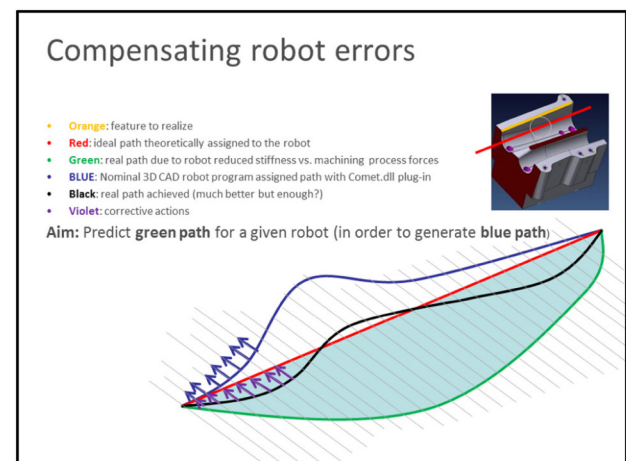


Figure 2. COMET process

So why does the robot go to a different place? Three sources of robot error are identified in [Figure 3](#). First there are the kinematic differences between the nominal robot used in the simulation, and the actual manufactured machine. Secondly the robot can also be moved by external forces, and finally there is backlash in the joints, apparent when changing direction.

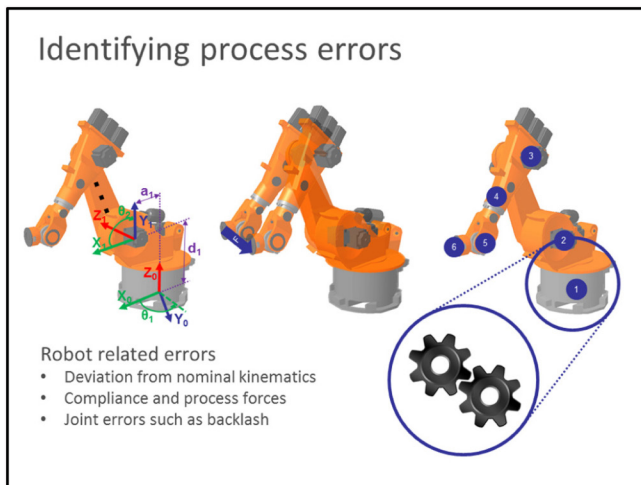


Figure 3. Sources of robot error

Measuring and modelling these sources of error allows us to predict variances. For “offline” the goal is to predict the error, and then change the robot target positions offline: to get a result in production closer to the 3D CAD nominal. So the path is modified shown in blue, in [Figure 2](#) with the predicted real path shown in black. It's not the same as nominal - but closer than the uncompensated path in green.

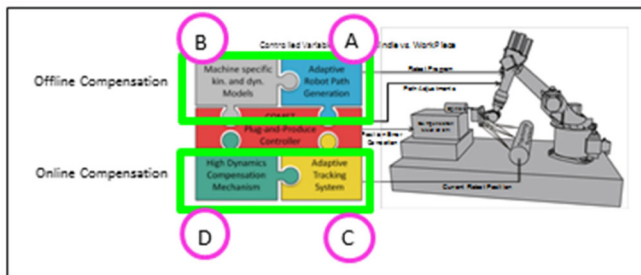


Figure 4. Project Structure

To facilitate Offline compensation, the simulated path (created in “A” in [Figure 4](#)) has a number of plug-ins to describe the actual robot kinematics and dynamics (“B” in [Figure 4](#)). These are shown below, and achieved by measurements (metrology).

The fundamental split between “offline” and “online” corrections are the use of coordinates in the robot controller. Online correction is based on original nominal 3D CAD, whereas offline correction changes the target positions “offline” before

they are loaded into the robot controller. Once the original targets are adjusted (Offline compensation) these cannot be used for online compensation because the targets are different. [Figure 5](#) shows the workflow adopted for Offline compensation. [Figure 6](#) shows the dialogue box in the CAM system to choose the compensation method. In this paper we will show results for kinematic calibration, joint based compensation, and a combination of them both. The other options are simplified versions of joint excitation.

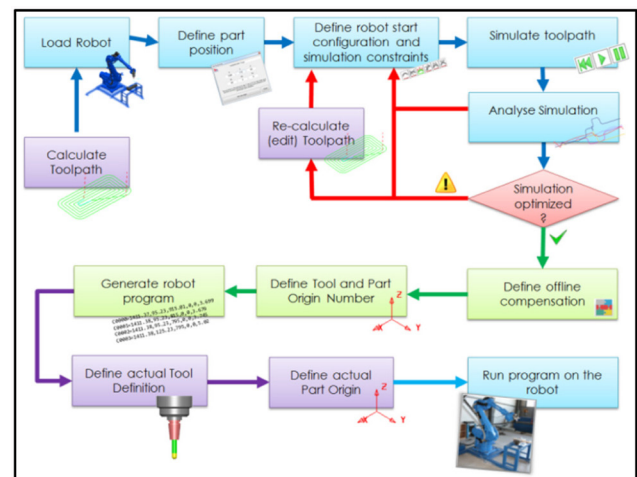


Figure 5. Offline compensation method

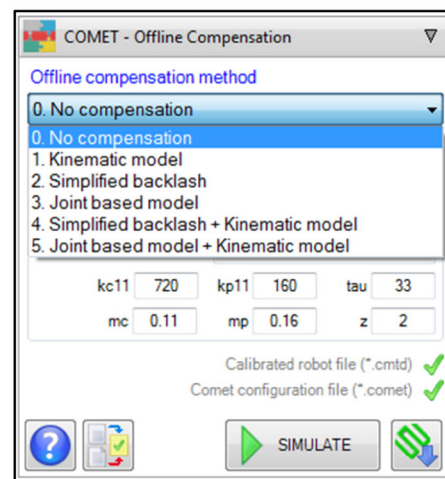


Figure 6. Options in CAM software

Kinematic Calibration

A solid state camera system was used from Nikon Metrology. It measures strobed IR LED's at frequencies up to 1kHz 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, as shown in [Figure 7](#).