Physical methodology of assessing 3D measurement uncertainties by Multi Levels Monte Carlo Simulation

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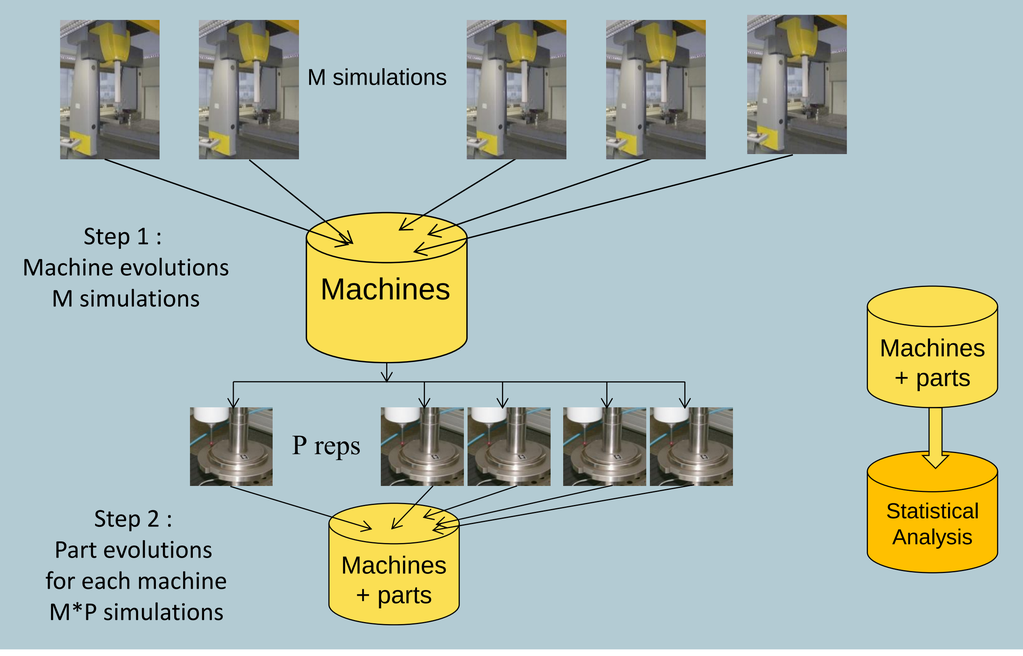
INTRODUCTION

For assessing the uncertainties on measurands studied, a **multi-level Monte Carlo approach** can be realized which allows being **near of the reality of the measurement process**.

The simulation is divided into several stages allowing understanding the phenomena; to identify the main sources of uncertainty...

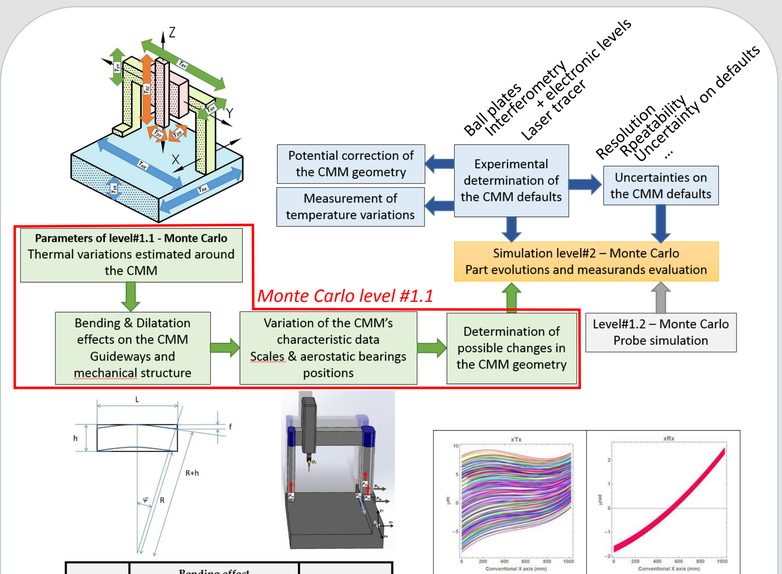
The objective of the simulation is to **create the set of possible measurement files** and have them run by the 3D software in order to simply calculate all the measurands. The generation of the files is carried out following the same approach as the actual measurement, that is to say that **the number of levels correspond to the important steps of the measurement process**

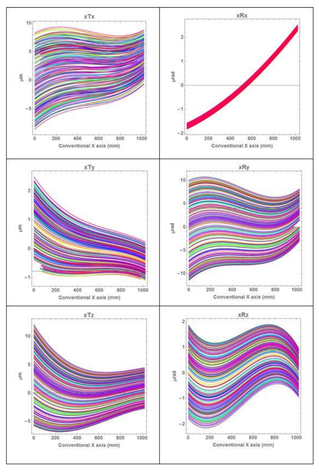
MLMCS: Multi Levels Monte Carlo Simulation Global principle in two principal steps



Virtual CMM

The different levels and details of the Level #1.1





Example of CMM geometry possible change for X-axis Level #1.1

Thermal variations	Bending effect		Dilatation effect on the axis
	Bending Value	Points directly impacted	
T_{VX}	$\frac{\alpha_X . L_Z^2 . T_{VX}}{8 . H_{Vx}}$	$P_{1x}\,(\vec{n}_z)$ $P_{2x}\,(\vec{n}_z)$ $P_{3x}\,(\vec{n}_z)$	
T_{HX}	$\frac{\alpha_X . L_Z^2 . T_{HX}}{8 . H_{Hx}}$	$P_{4x}\,(\vec{n}_y)$ $P_{5x}\,(\vec{n}_y)$	
T_{RX}			$\alpha_{Rx} . T_{RX} . x$
T_{VY}	$\frac{\alpha_Y . L_Z^2 . T_{VY}}{8 . H_{VY}}$	$P_{1y}\,(\vec{n}_y)$ $P_{2y}\,(\vec{n}_z)$ $P_{3y}\,(\vec{n}_z)$	
T_{HY}	$\frac{\alpha_Y . L_Z^2 . T_{HY}}{8 . H_{HY}}$	$P_{4y}\,(\vec{n}_x)$ $P_{5y}\,(\vec{n}_x)$	
T_{RY}			$\alpha_{Ry} . T_{RY} . y$
T_{dx}	$\frac{\alpha_Z . L_Z^2 . T_{dx}}{8 . H_{dx}}$	$P_{1z}\,(\vec{n}_y)$ $P_{2z}\,(\vec{n}_y)$ $P_{3z}\,(\vec{n}_y)$	
T_{dy}	$\frac{\alpha_Z . L_Z^2 . T_{dy}}{8 . H_{dy}}$	$P_{4z}\,(\vec{n}_x)$ $P_{5z}\,(\vec{n}_x)$	
T_{RZ}			$\alpha_{Rz} . T_{RZ} . z$

Example: Effects of TVX on the X-axis

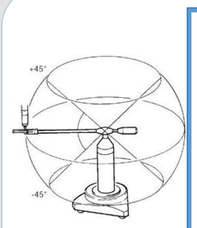
Deformation of the granite is parabolic:

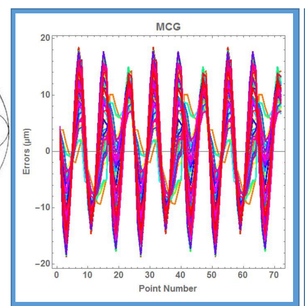
$$\begin{cases} \frac{\alpha_X . Lx^2 T_{VX}}{8\,H_{VX}} \left(1 - \left(\frac{\overrightarrow{X_1 P_{ix}} . \overrightarrow{nx} + x - \frac{Lx}{2}}{\frac{Lj}{2}}\right)^2\right) = \left(\vec{\varepsilon}_{O_j} + \overrightarrow{w_j} \wedge \overrightarrow{O_j P_{ij}}\right) . \overrightarrow{n_{Pij}} \text{ with i} = \{1 \text{ to } 3\} \text{ and } \overrightarrow{n_{Pix}} = \overrightarrow{n_z} \\ 0 = \left(\vec{\varepsilon}_{O_1} + \overrightarrow{w_x} \wedge \overrightarrow{O_1 P_{ix}}\right) . \overrightarrow{n_{Pix}} \text{ with i} = \{4 \text{ to } 5\} \text{ and } \overrightarrow{n_{Pix}} = \overrightarrow{n_y} \\ 0 = \left(\vec{\varepsilon}_{O_1} + \overrightarrow{w_x} \wedge \overrightarrow{O_1 P_{6x}}\right) . \overrightarrow{n_{P6x}} \text{ with } \overrightarrow{n_{P6x}} = \overrightarrow{n_x} \end{cases}$$

Thermal Variations	Degree of polynomial	xTx	xTy	xTz	xRx	xRy	xRz
T_{VX}	0	Drift	Drift	Drift	Torsion	Perpendicularity	
	1	Linear accuracy		Perpendicularity		Camber X	
	2			Vertical camber			

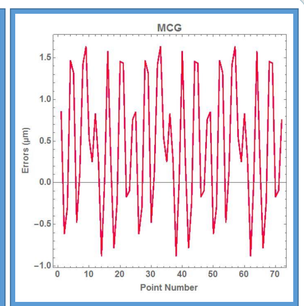
Thus it is possible to know the consequences of the design of the machine on its deformation as a function of temperature variations

Awareness on the effects of drift on MCG measurement





Simulation close to physics with highlighting drifting problems

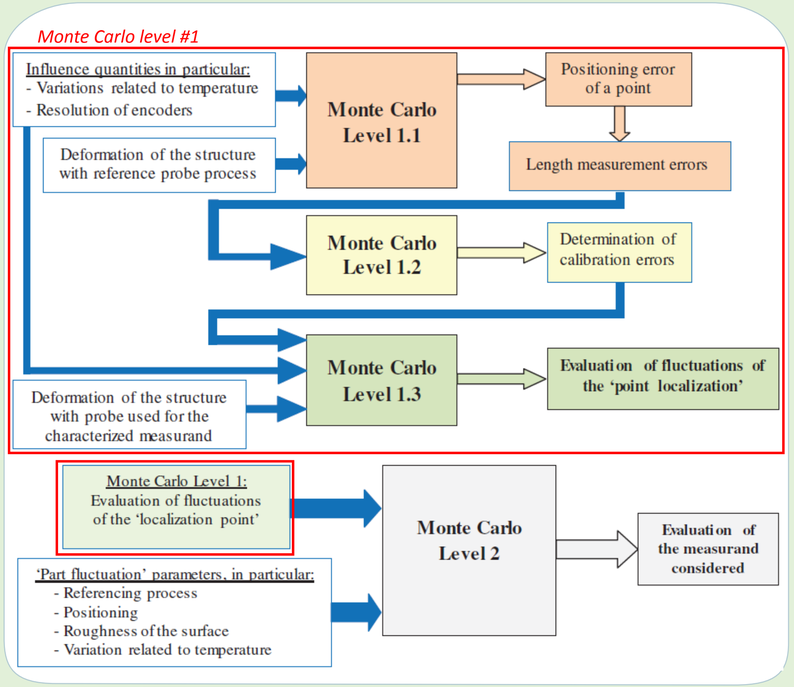


The same simulation by removing the effects of drift

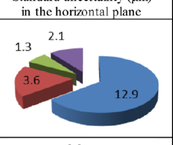
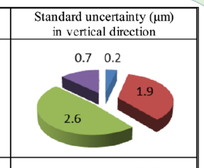
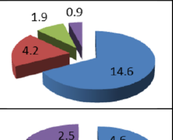
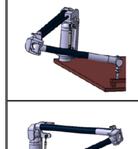
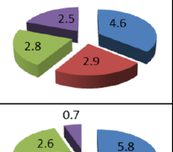
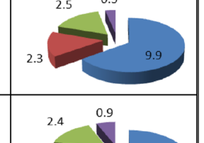
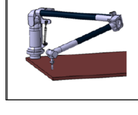
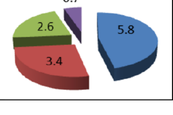
Sponsors: cetim, ZEISS, cea

Virtual AACMM

The different levels



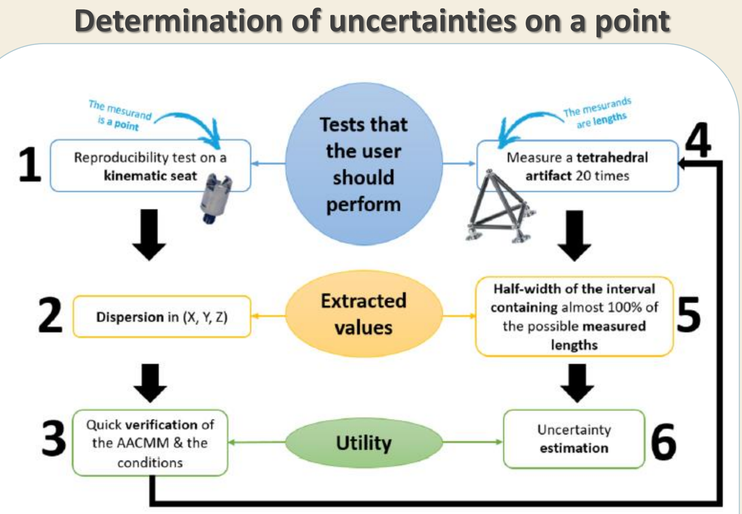
Evaluation of a Romer 2025 Sigma Arm

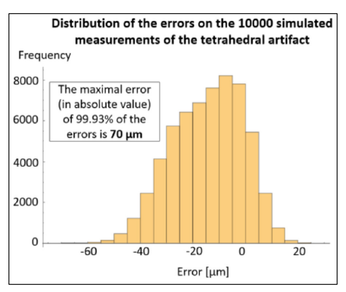
Positions considered	Standard uncertainty (µm) in the horizontal plane	Standard uncertainty (µm) in vertical direction
		
		
		
		

Sponsors: cetim ROMER, HEXAGON METROLOGY

Global evaluation of uncertainties practically on AACMM

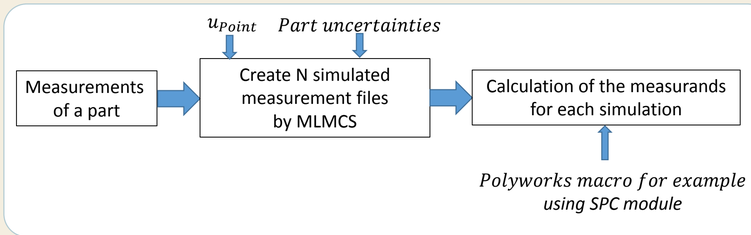
Determination of uncertainties on a point





$$u_{Point} = \frac{u_{Length}}{\sqrt{2}} = \frac{Maximal\ error\ simulated}{\sqrt{6}}$$

Method to determined uncertainty on mesurand



Sponsors: Kreon, PolyWorks, cetim

Synthesis on virtual machine concept

Benefit	Disadvantage
Allows to a manufacturer to better evaluate its uncertainties and improve its device	Not feasible (realistic) for a standard user because he knows neither the model used nor the compensations used by manufacturer

Concept of Virtual Machine is interesting for the manufacturer but inadapted for user

Synthesis on practical assessment

Benefit	Disadvantage
Easily achievable by any user taking into account the operator and the environment	Majore the uncertainties

Synthesis on MLMCS

Simulation closer to physics.
Only realistic simulation but requires manufacturer collaboration

Other developments

Pratical uncertainty assessment for tracker laser

General Electric, PolyWorks