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Integration of Dimensional and Thermal Metrology In the Light Controlled Factory

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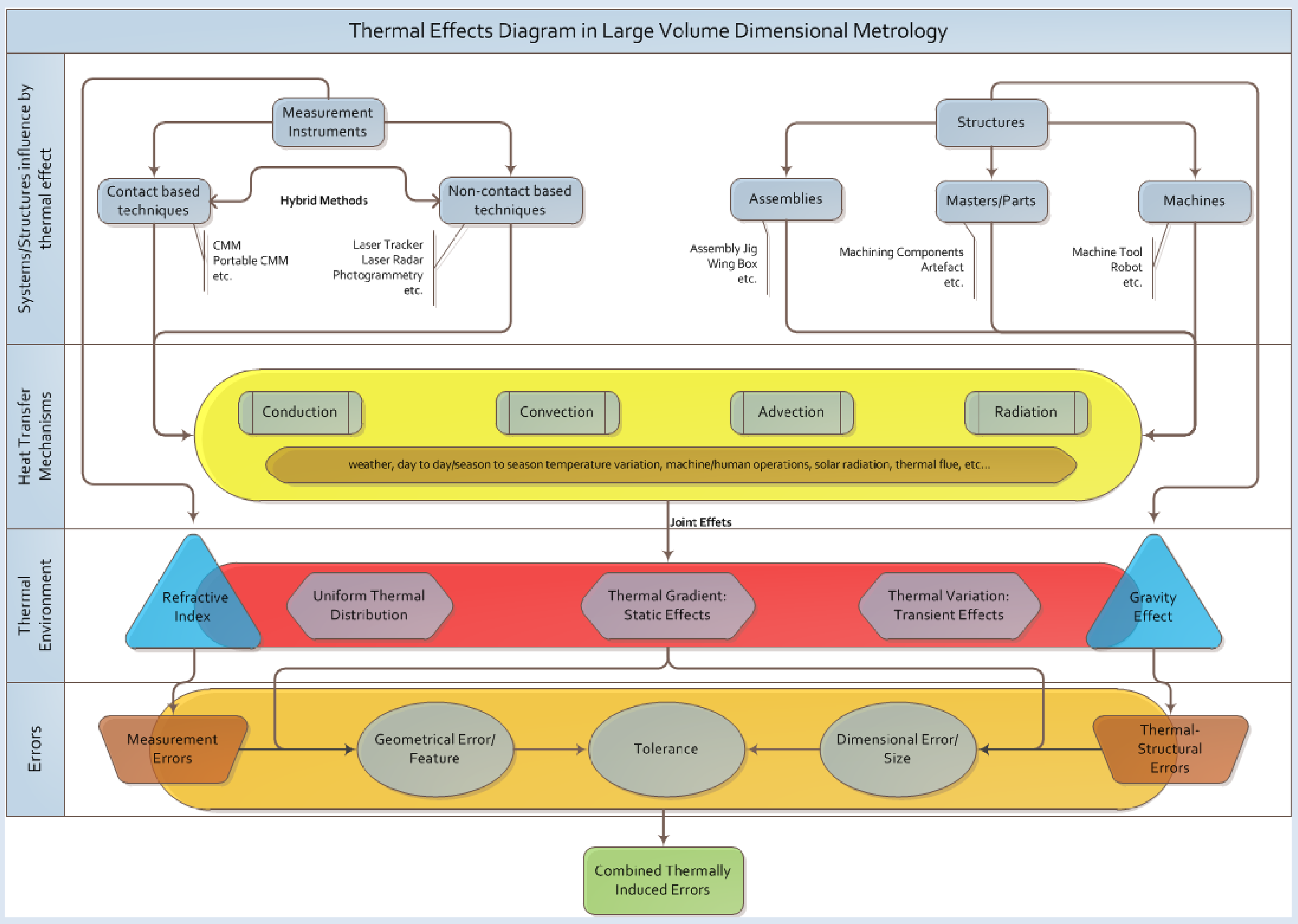
Introduction

The assembly of large aerospace structures often take place in uncontrolled production environment which leads to thermal distortion due to temperature variations (typically 6-10 °C across the workplace). When measuring critical features on these large, complex structures in assembly, thermal issues have significant influence on measurement accuracy. The positional accuracy is also affected by gravitational sag, mechanical loads, multiple constraints and contacts making the measurement compensation even more difficult. These nonlinear behaviours lead to significant uncertainties during the measurement and assembly process. Currently systematic understanding, analysis and compensation solutions for these effects are very limited. For the next generation assembly technique, an in-process thermal compensation solution has become pressing when high accuracy measurements need to be achieved. This requires an active integrated measurement of displacement and temperature of the structure across the boundary, and an efficient and accurate computational model to predict the structural behaviour. Research at LIMA, University of Bath is being done to develop new techniques and methodologies to model thermal variation through a combination of physical measurement and computational methods.



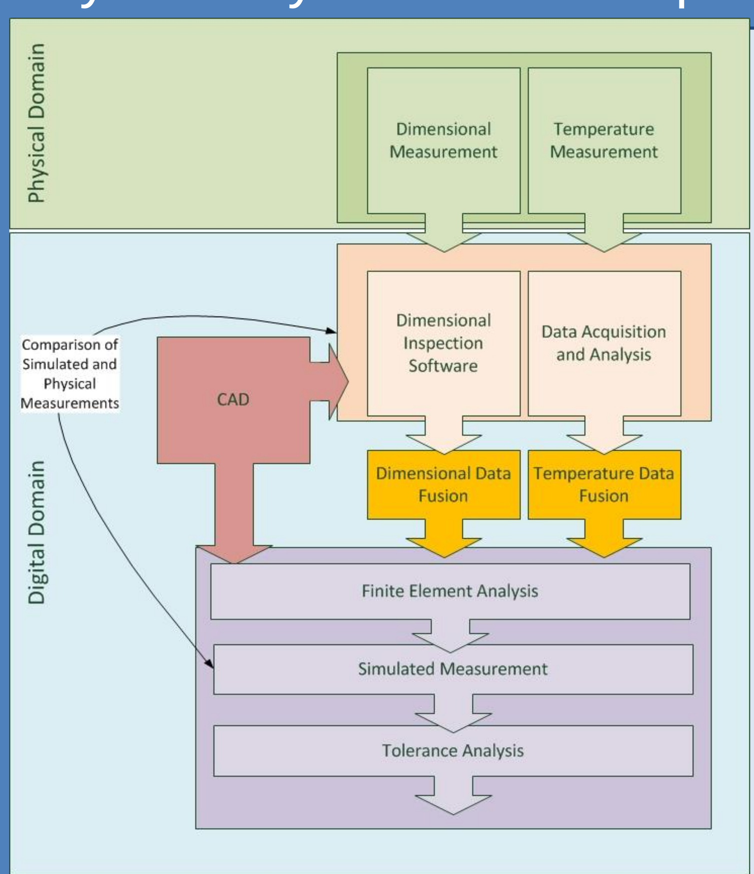
Objectives

Develop measurement methodology and conduct case studies from measuring simple structures to multi-component assemblies in the laboratory, which is a represent action of an uncontrolled production environment.

Develop an efficient computational method to simulate and predict structural behaviour under thermal gradients and mechanical loadings.

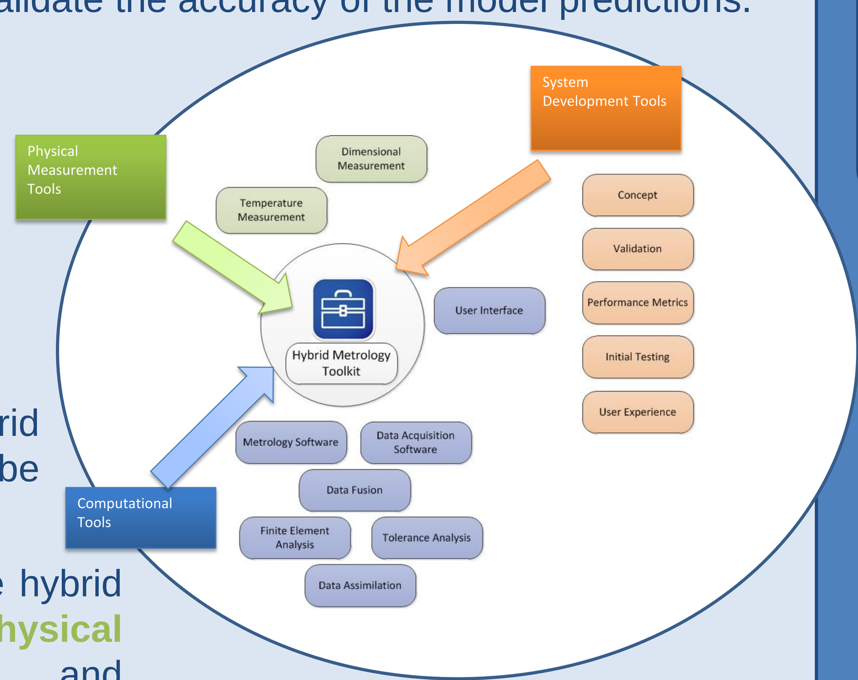
Develop an uncertainty evaluation method using both measurement and simulation and integrate computational prediction results into tolerance propagation for measurement compensation.

Hybrid Physical and Computational Metrology Concept



The hybrid metrology system combines physical dimensional and temperature measurement with computational methods to predict structural deformations attributable to thermal and gravitational loads in the AIT environment which can be used to evaluate resultant effects on the tolerance stack up of an assembly. These simulated values can be compared to physical measurement values to validate the accuracy of the model predictions.

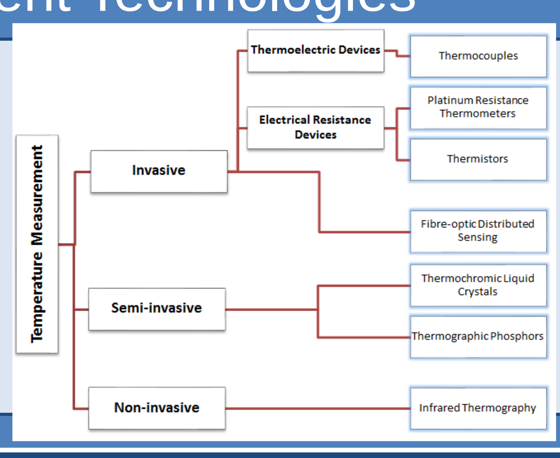
This is one example configuration of a hybrid metrology system, but other techniques could be used.



A number of 'tools' can be used to realise the hybrid metrology concept that are grouped into **physical measurement tools**, **digital tools**, and considerations for **system development**.

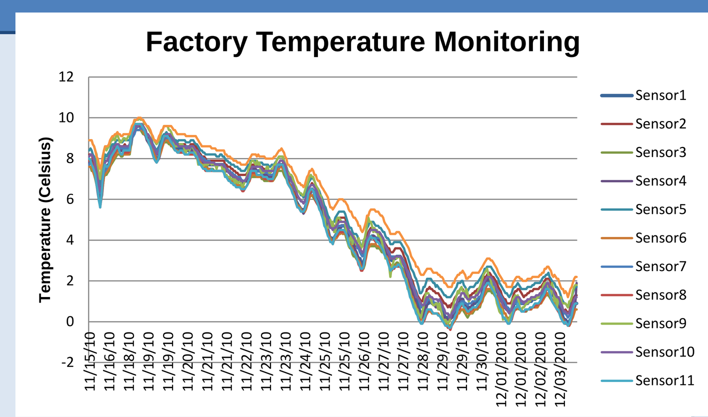
Identification of Temperature Measurement Technologies

Key temperature measurement technologies have been identified that are commercially available which can operate in the range between 0-50˚C. During the development of the system, invasive sensor types are being used and less invasive sensor types will be used more frequently as the system matures.

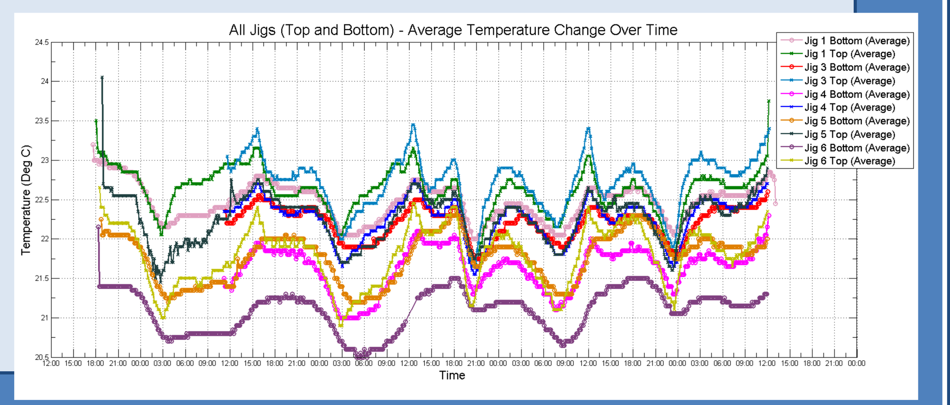


Assembly, Integration and Test Thermal Variation

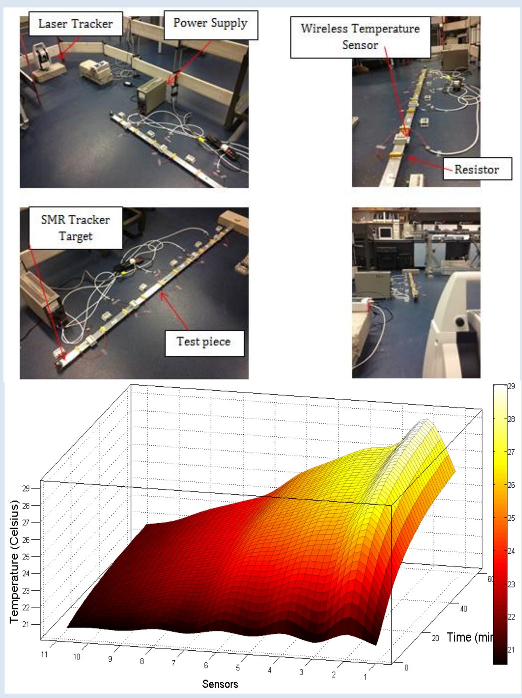
Temperatures were measured in different positions of a wing assembly jig over a two week period in an **uncontrolled** environment. A maximum ambient temperature of 10°C and the minimum temperature of -0.5°C with a maximum gradient about 3°C were observed across the height of the structure during the measurement period.



In contrast, temperatures were also taken over the course of a working week within a temperature **controlled** environment at a different site, showing a temperature difference of around 2˚C at any given time with a variation of around 1.5˚C over a 24 hour period.



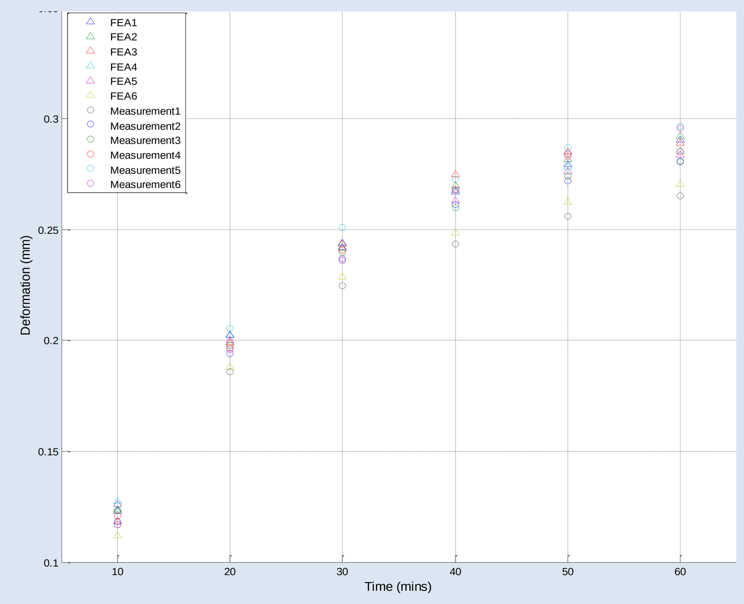
Case Studies

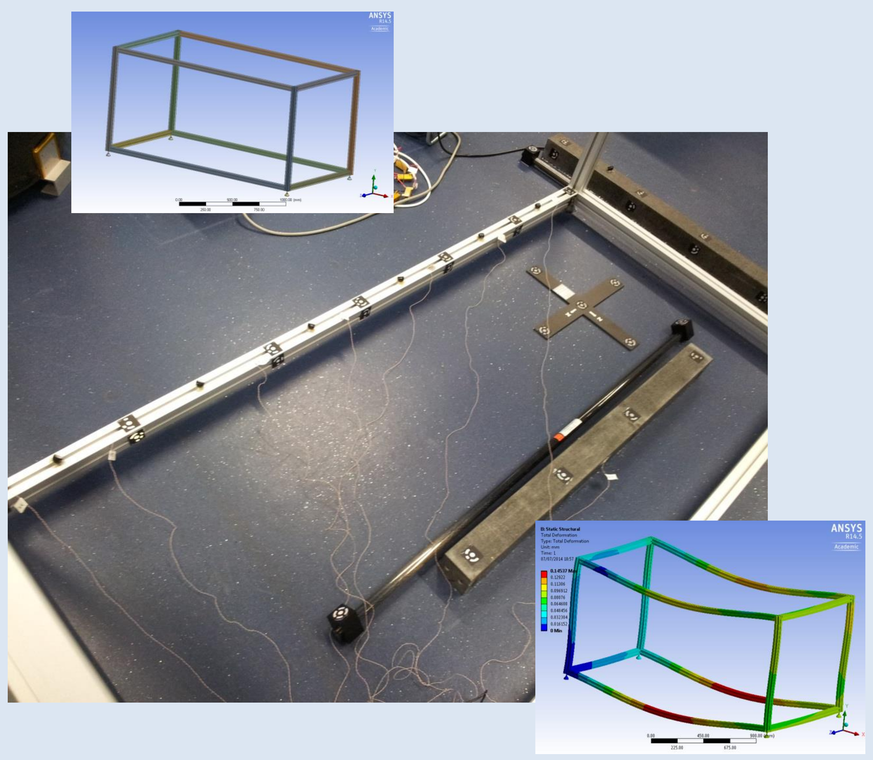


An experimental study was first carried out to measure temperature and deformation of an aluminium beam which was supported by ball bearings underneath, rigidly constrained at one end by being attaching to a concrete block which forces the beam to only grow in one axial direction. 10 resistors were mounted uniformly on the top surface and connected in parallel to make 5 heating stations (5 pairs of resistors) powered by an adjustable power supply. Temperature sensors were mounted on these resistors as well as on the surface of the beam between the 5 heating stations. A laser tracker SMR target was mounted at the end of the structure which allowed the maximum axial displacement to be measured. In order to simulate and represent the environment of a factory/assembly site, a 5-10°C temperature gradient was introduced to the test piece.

Summary:

- Heating lasted 60 minutes and measurements were repeated 6 times
- Laser tracker measurement uncertainty 21µm, temperature measurement uncertainty 0.2°C.
- Thermal gradient (20-29°C) was introduced by heat conduction. Maximum thermal deformation in x: 296µm
- It has proved less than 5% inaccuracy between FEA predictions and measurements can be achieved.
- The worst case study was conducted by introducing a 10% uncertainty to the key model parameters such as material CTE, thermal conductivity, thermal loading and initial temperature condition, which gives an additional ±25 µm to the prediction results. Inaccuracy increases to about 10%.





Work is currently focused on a complete structure: a MiniTec aluminium 6061 frame. Initially, the tests will be conducted on a single constrained beam within the frame, eventually leading up to modelling the entire frame structure. Subjected to thermal and gravitational loading, dimensional measurements will be carried out using a laser tracker and photogrammetry system combined with type T thermocouple temperature measurements and compared to simulation predictions of structural deformation.

Conclusions

As product specifications become more demanding it is clear that methodologies for managing thermal and gravitational effects are increasingly important. A theoretical framework is being developed and potential technologies have been identified for its implementation. Early studies have shown that a hybrid physical measurement and computational approach represents a promising step towards the improvement of product integrity in uncontrolled environments.

Future Work

Further studies need to be carried out on increasingly complex and larger scale structures to develop and validate the hybrid metrology system with increased emphasis on tolerance analysis of assemblies. The integration of thermal metrology into product lifecycle management (PLM) is also vital to the adoption of this technology in industry.

Acknowledgements

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[1] D. Ross-Pinnock, P. G. Maropoulos, *Identification of Key Temperature Measurement Technologies for the Enhancement of Product and Equipment Integrity in the Light Controlled Factory*, Procedia CIRP of The 8th International Conference on Digital Enterprise Technology, Stuttgart, Germany 2014

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