The Application of Automated Planning to Machine Tool Calibration

S. Parkinson[1] A. P. Longstaff[1] A. Crampton[2] P. Gregory[2]

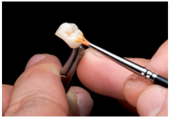
[1]Centre for Precision Technologies

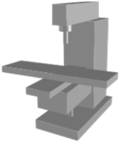
[2]Department of Informatics
School of Computing and Engineering
University of Huddersfield, UK

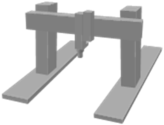
ICAPS, 2012

Introduction

- A machine tool is a mechanically powered device used for manufacturing components.
- Machine tools are typically designed for optimum manufacturing of a small range of components. Hence the variety of different machines.
- Optimised in terms of size, material and power.





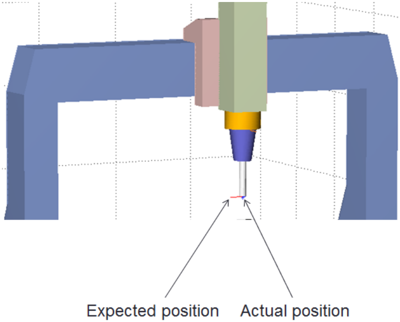
Introduction

- The demand to manufacture parts to an ever increasing degree of accuracy has resulted in the requirement for achieving the best possible accuracy from machines.
- Therefore, calibrating the machine is essential to gain an understanding of its accuracy.
- Increased accuracy = increased cost.

- Working volume of 4.5 m x 5 m x 1.5 m with an accuracy of 20 µm
  - Average human hair diameter $\sim$ 70 µm

Introduction

- All machine tools have errors.
- Machine tool calibration is the process of examining a machine's behaviour using a set of standard tests methods.
- From this we can establish the machine's predictability.



Machine Tool Calibration

- Performing a machine tool calibration is an expensive task, so getting it right first time is essential.
- Bad data can result in the production of bad parts or incorrect removal from service.
- Therefore, expert knowledge is certainly required.

- 72 m gantry machine for manufacturing the fuselage for the AirBus A350

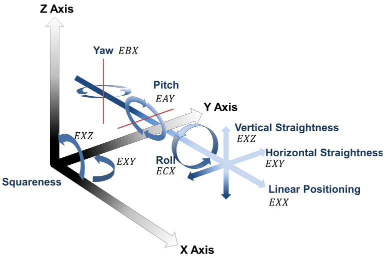
Machine Tool Calibration

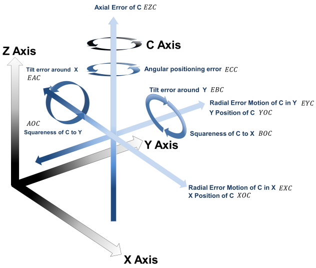
- Machine tool calibration contains the following sub processes:
  - Analyse machine's configuration
  - Prioritise
  - Select the best method of measurement
  - Select the best equipment for the measurements

Machine Tool Calibration

Geometric errors

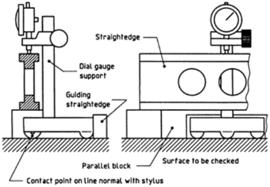
- Linear and rotary axes have different geometric errors.
- A machine tool is typically constructed from a combination of linear and rotary axes.
- The stacking order of these axes changes how the errors manifest down the kinematic chain.

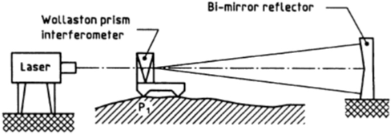




Measurement Methods

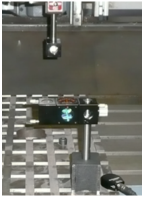
- There are many different methods of measuring the same error component that use different equipment.
- For example, here are two ISO method for measuring straightness.





Measurement Methods

- Multiple measurement techniques can use the same instrumentation with only small adjustment.
- E.g. changing the optics of a laser interferometer to test for a different error component.
- Laser is already aligned parallel to the y-axis.
- The optics are aligned with the laser.
- Carefully swapping the optics will result in little adjustment of the laser.




- Readjustment time is typically lower than the time taken to setup from scratch E.g. 3 minutes adjustment time over 15 minutes setup time.

Concurrent Methods

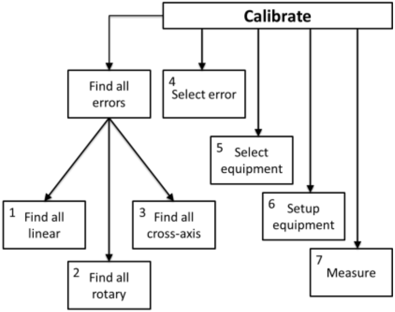
- The situation can arise where it is possible to perform multiple measurements at the same time
- For this to occur, there are many preconditions;
  1. No physical restrictions of the machine and its environment.
  2. No instrumentation interference.
  3. Identical or compatible measurement parameters (feedrate, stepsize, target count)

Automated Planning

- To minimise machine downtime, automated planning techniques can be used to produce an optimised calibration plan.
- Modelling techniques investigated:
  - Hierarchical Task Network (HTN) – SHOP2
  - Planning Domain Definition Language (PDDL) – LPG-td

HTN Model

- The HTN model was designed and tested using the SHOP2 architecture.
- The motivation behind the selction was because machine tool calibration can naturally be expressed as a sequence of smaller tasks.



PDDL Model

- The HTN model was then modified into an PDDL encoding so that many different state-of-the-art planning algorithms could be used.
- The model uses several different PDDL requirements:
  - Quantification, numbers, time and timed initial literals.
- In our model we use durative actions (PDDL 2.1).

PDDL Model: Temporal Constraints

1. All instruments that are set-up must be set-up on the same axis.
2. Each instrument has a maximum number of tests which it can perform simultaneously.
3. On each axis it is not possible to use certain equipment simultaneously. For example, instrument interference.
4. Testing can happen over a number of days. However, all tests conducted on each day must be contained within an eight hour period.

PDDL Model: Spatial Constraints

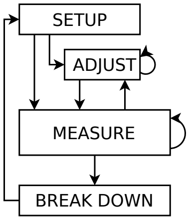
1. In some cases, is it possible that the machine's design or location impose physical restrictions which prevent the use of certain instrumentation.
2. The operating range of an instrument must be greater than the desired measurement range.

PDDL Model: Operators

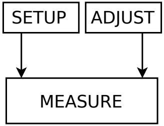
In our model there are three types of objects

1. Axis,
2. Instrument,
3. Error.

The following diagrams show at a high level how the operators manipulate the objects.



Instrument Object



Error Object

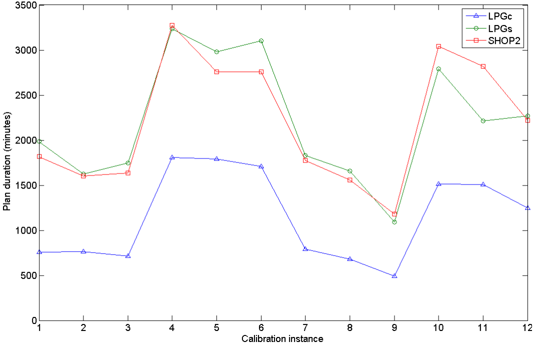
PDDL Model: Plan Metric

- **Time**: Using the times specified in the initial state, we can minimise the total-time required to reach the goal.
- **Importance**: Each error component has a different importance depending on the machine's configuration. When there is insufficient time to perform a full machine calibration, it is desirable to measure the most important errors within the given time frame.
  - To do this we maintain a 'global importance' fluent that sums the importance of each error component measured in the plan.

PDDL: Model : Intial and Goal State

- Initial State - Predicates and Fluents
  - Set-up and adjustment times for each instrument.
  - Which instrument can measure which errors.
  - The errors which need to be measured.
  - The importance of each axis and error.
- Goal State
  - Each error component that needs to be measured.
  - Or, for the optimisation version, where we maximise the importance of the errors measured, we pose an empty goal.

Results: Model Comparison

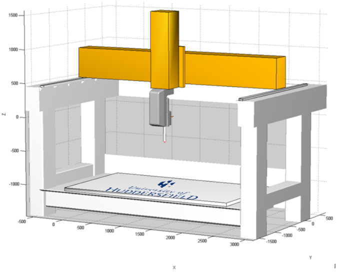


- 12 different calibration scenarios
- HTN and PDDL results are similar
- Pleanning for concurrent measurements significantly decreases the calibration plan

Case Study

Five-axis gantry machine

- Industrial Expert's plan
- Academic Expert's plan
- HTN produced plan
- PDDL produced plan



Linear errors	21
Rotary errors	16
Spindle errors	4
Total	41

Expert's Plan

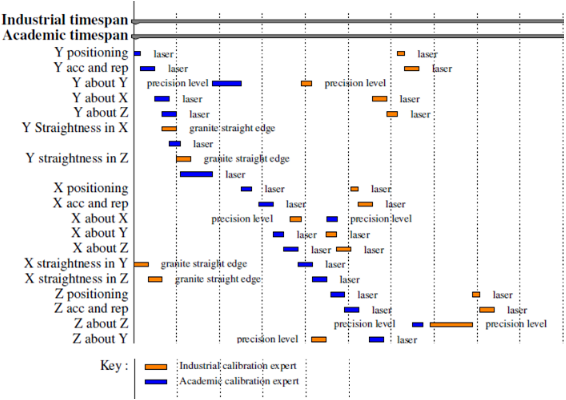
1. Both plans are significantly different in terms of ordering, test duration and equipment selection
2. Different motivation: The academic's plan is focused towards capturing all the data and analysing later, whereas the industrial plan is ordered in the way that the geometric errors manifest though the machine's kinematic chain.

Calibration Plan	Time in hours
Industrial expert	12:30
Academic expert	13:30

Plan

Industrial and Academic

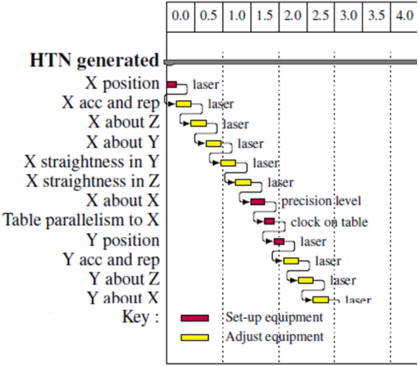
- Industrial expert - manifest errors.
- Academic expert - most difficult first.



Plan

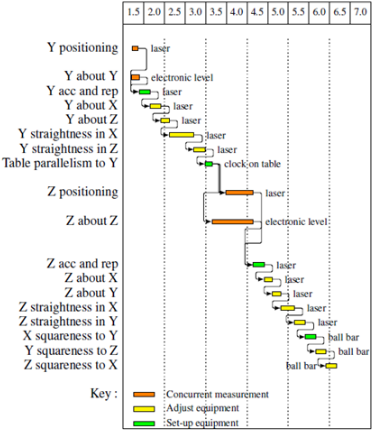
HTN

- Measurements are planned sequentially
- Grouped by axis
- Optimisation has reduced instrumentation set-up



Plan
PDDL

- Some measurements are still performed sequentially, but where possible concurrent measurements have been planned.
- Grouped by axis
- Optimisation has reduced instrumentation set-up



Plan

Comparison

1. The PDDL concurrent plan is the best in terms of duration.

Calibration Plan	Time in hours
Industrial expert	12:30
Academic expert	13:30
HTN	12:10
PDDL	11.18

Summary

- The challenge of machine tool calibration planning has been modelled in PDDL and HTN suitable for SHOP2.
- Comparisons with expert plans have displayed the potential for reducing machine down-time.

- Outlook
  - So far, only the small section of machine tool geometric errors have been modelled.
  - Calibration plans can be optimised to reduce time, but they can also be used for increasing measurement traceability and reducing measurement uncertainty

Thank you for listening
Any Questions?
s.parkinson@hud.ac.uk