

Changeable, Agile, Reconfigurable & Virtual Production

## Roadmap for deploying semantic GD&T in manufacturing

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### Abstract

A five phase roadmap is proposed for deploying semantic GD&T in manufacturing. In the first phase real manufacturing is connected to virtual manufacturing using protocols such as MTConnect. In the second phase the virtual manufacturing results are connected to virtual and real CMM's. In the third phase new services optimize the models to make them more efficient while still meeting their design requirements. In the fourth phase closed loop machining systems evaluate proposed changes in real time. In the fifth phase the usage of cloud based models in virtual twin factories becomes ubiquitous. We describe how the virtual twin factories are built in Node.js, and how a new suite of protocols called the SWIM is used to track the relationships between normalized STEP models and the easy to use JSON objects of the virtual factory.

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### 1. Introduction

Today's shop floor is a place where skilled operators convert drawings into machined parts. The methods used to interpret the drawings, generate the machine codes and inspect the results are largely unknown to the rest of the enterprise. This paper proposes using standards to expose them to others so that they can be made more efficient. The key standard is AP242 because it allows the manufacturing requirements to be shared as semantic dimensions and tolerances [1]. With this standard it becomes possible to measure the shop floor solutions against how well they are meeting their design requirements. The other standards are MTConnect for reporting the run time machining results [2], QIF for evaluating the measurements [3] and STEP-NC for sharing the manufacturing solutions [4]. Figure 1 illustrates how they are being assembled into a system for transparent, inspected machining.

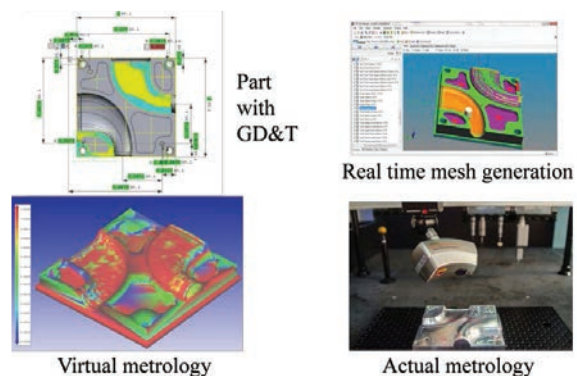


Fig.1. Components of a transparent manufacturing system: (a) Design requirements as semantic GD&T (AP242); (b) real time mesh generation from MTConnect data; (c) virtual metrology of the virtual mesh to make QIF; and (d) real metrology of the machined part.

## 2. Roadmap

Figure 2 is a roadmap for deploying the technology. The first phase is to enable remote monitoring of machining on smart phones and tablets. A demonstration is being developed to show this capability at the Future of Flight Museum in Mukilteo, Washington on October 5<sup>th</sup> 2016. A preview is available at: <http://www.steptools.com/demos/mtc/>. For this stage the current state of a machined part is shown in real time. First, the latest coordinates of the machine tool are transmitted using MTConnect. Second, a simulator applies them to STEP models of the manufacturing product and process. Third, the updated models are sent to the phone along with information about how the machining can be made more efficient by reducing tool wear or increasing the feeds.

The online demonstrations also show some aspects of the second phase. The full second phase is to enable virtual measurement of the virtual models. The enabling standard (AP242) is being deployed by the CAD and CMM vendors. The risk for this phase is that the new systems will not be able to produce a virtual model that is sufficiently accurate for worthwhile measurement. Factors that may impact the virtual modelling include (i) being able to reliably measure the setup coordinates and tooling dimensions, (ii) being able to estimate errors due to tool bending and CNC inaccuracies, and (iii) being able to model the result with sufficient fidelity while keeping the data volume manageable.

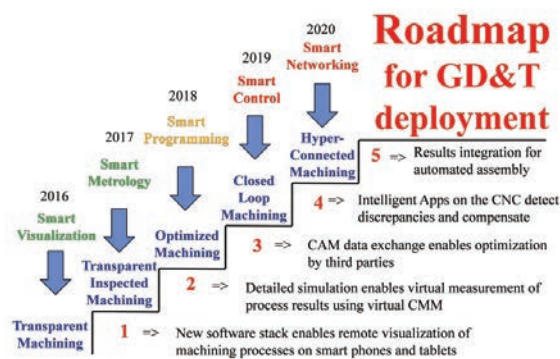


Fig.2. Roadmap for GD&T deployment

## 3. Pathway to Implementation

Paper calculations backed up by experiments show that the error in a path approximated from MTConnect measurements decreases proportionally to the square of the sampling rate. For example, an approximation error of 0.4mm for a 1 second sampling rate is reduced to 0.1mm if the sampling rate is doubled. We are finding that a sampling rate of 100ms is not sufficient to capture rapid moves accurately, but 10ms is sufficient, and many CNC machines may soon be able to report their position at 1ms rates.

If the setup and tool dimensions are measured accurately and the sampling rate is good, then the remaining errors are due to the machining forces and their impact on the tools and

the CNC. A simulator connected to the machining can calculate the speed and profile of the cut. A database of previous job / material / force combinations connected to a machine learning system can predict results for the next cut. Figure 3 shows some of the data paths being established.

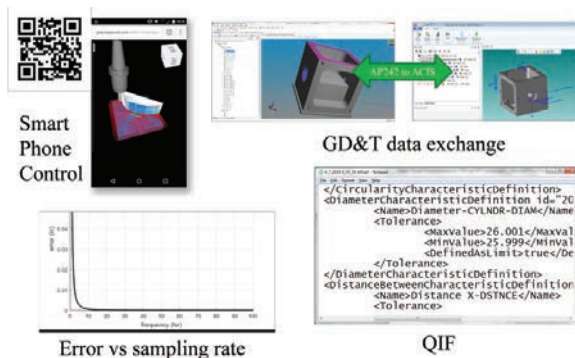


Fig.3. Early results for the October demonstration (a) smart phone display; (b) the test part with semantic GD&T; (c) graph showing relationship between sampling frequency and measurement accuracy; (d) first QIF metrology results for the test part.

The third phase of the roadmap uses the results of the first two phases to enable third party optimizations. In this phase remote systems have the ability to monitor machining programs, and measure their results using virtual and real coordinate measurement machines (CMMs). Therefore, third parties will be able to optimize manufacturing solutions by making suggestions for process improvements. For example in an experiment at IMTS 2104, two cutter vendors made a model based machining program 15% better by substituting better tooling [4]. In 2018 the roadmap anticipates that this optimization will start to take place at industrial sites using a mixture of CAD/CAM data exchange and new cloud services.

In order to enable third party optimization there must be accurate monitoring of results. Therefore, experiments are being organized in which streams from multiple data sources are compared to validate processes. Sound is simple though it may be better to measure the spindle force directly. If there is no sound when the coordinates show the tool should be cutting metal then the setup is wrong. If an increase or decrease in volume does not correspond to a change in the depth of the engagement then something else is wrong. Predictions that prevent damage will be highly valued.

The fourth phase requires two innovations. The first is full modelling of the machine tool including both the CNC and PLC components. This modelling is necessary so that a complete simulation of the machining can be optimized by third party apps. The second innovation is the connection of the QIF output of Figure 3 to the STEP inputs. Today an operator understands the machine and is able to watch for discrepancies. The goal of the fourth phase is to enable intelligent apps that do the same thing.

The risk for the third phase is implementation of the necessary CAM translators. The risk for the fourth phase is being able to model the internal logic of each machine in a language like JavaScript. The risk for the fifth phase is reaching consensus on the standards necessary for all of the models. This consensus is necessary so that the models can be

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