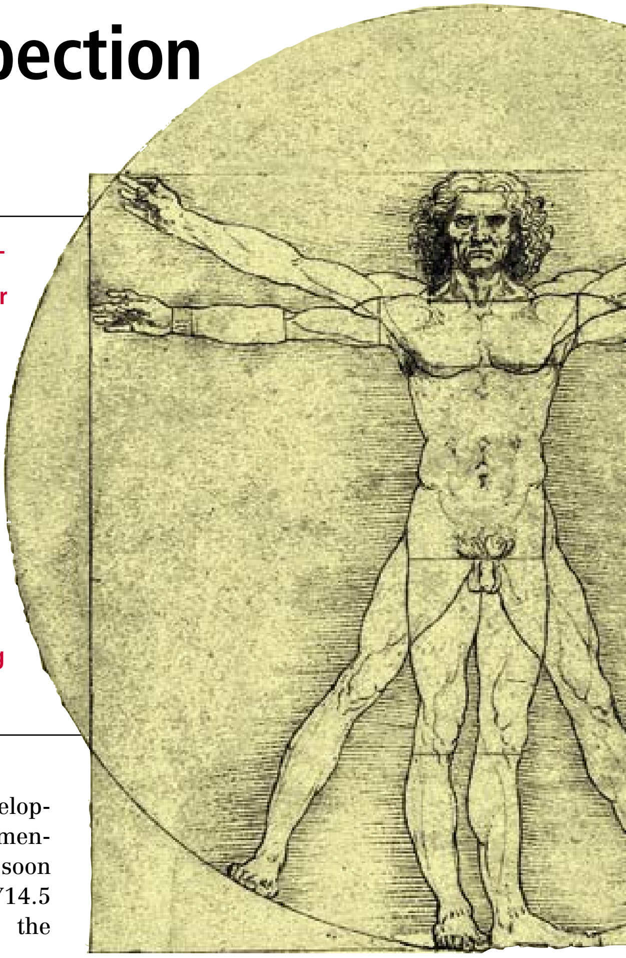
A Paradigm Shift for Inspection

Complementing Traditional CMM with DSSP Innovation



Advances in non-contact measurement technology, processes and techniques have created momentum in the application of digital shape sampling and processing (DSSP) for driving a competitive advantage for manufacturing in a variety of industries from automotive and aerospace to consumer products. DSSP has been defined as the convergence of 3D scanning and digital processing of coordinate points by the Society of Manufacturing Engineers in an SME Bluebook authored by Peter Marks of Design Insight and published in October 2005. This paper will demonstrate how DSSP, a potentially disruptive technology innovation, complements traditional inspection methodologies without being disruptive. This paper will also show how inspection is evolving by integrating multiple methodologies to benefit manufacturing productivity and improve product quality to new levels.

A Survey of Technology

When Leonardo da Vinci was designing his advanced machines, there was no concept of manufacturing tolerances or quality inspection measurements. In the 19th century the approach was not different than from Leonardo's time: "cut and try, file and fit".

At the turn of last century, the concept of "Plus and Minus" tolerances was developed and around 1920, the "Taylor Principle" that defined the functional requirement for assembly was introduced.

During the Second World War development commenced on geometrical dimensioning and tolerancing (GD&T) and soon thereafter, 1957 saw the light of Y14.5 which evolved to prominence in the present day (ASME Y14.5-1994).

Historically, manual gauges have been used as main tools in metrology, from go/no-go (hard) gauges (such as a simple pin with a given diameter to determine fit), to numerical manual calipers to take measurements from point to point. Hard gauges come in different sizes for different applications, including measuring small turbine blades, car doors and airplane doors. The process includes the use of reference geometry (datums) to position the part to be measured, and then using pass/fail hardware (pins, contact pins, etc.) to measure key characteristics. While very easy to use, the hard gauges are not flexible to accommodate design changes and generally provide only qualitative information (pass/fail) rather than quantitative information (numerical value).

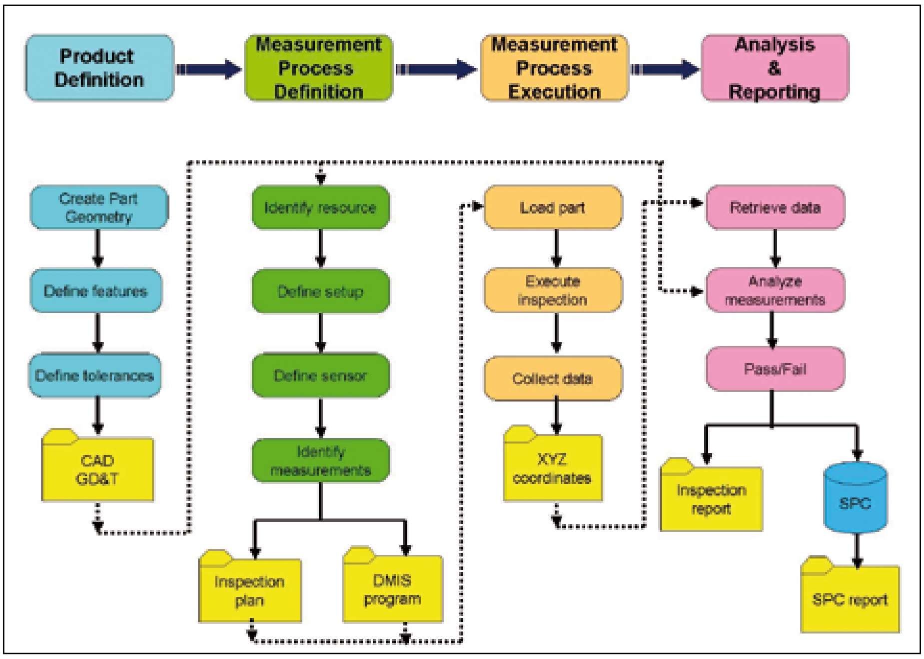


Fig. 1: Traditional CMM-based inspection workflow diagram

In the past 30 years, coordinate measurement machines (CMMs) were introduced, and now are widely used to take measurements in the manufacturing industry. A CMM is a programmable 3–4 axis machine that, through the contact of a touch probe, follows a path to inspect a part at predefined points. Adding accuracy, repeatability, automation and flexibility, CMMs are being used to measure small parts as well as large parts, with generally very high accuracy. They are quite expensive, but they are also quite flexible in their ability to be programmed to inspect virtually all types of parts.

Using CMM in a typical method, a series of characteristics is planned to be measured and an inspection program is created to measure those identified characteristics. The drawback of the CMM

method is that, in only collecting one single point at a time, the point-collection process results in a relatively slow measurement process. Due to inherent time constraints in this process, often only a few critical characteristics can be measured, and as a result, some inspection risks are taken to maintain required production levels.

Photogrammetry has a history of being used to measure terrain and distances for GIS and volumes of buildings – in AEC and archeological applications. The technology, based on techniques of measuring objects from photogrammes, has evolved and increased in accuracy over time so that it is effectively used in measuring large, mechanical objects (e.g. ships and airplanes). However, in the discipline of Quality Assurance where accuracy is of utmost importance, the limitation of insufficient accuracy realized in metrology applications is a critical factor.

Recently, new non-contact measurement technologies that use scanning hardware and processing software to digitally capture physical objects and automatically create accurate 3D models are increasingly used and deployed in the area of metrology. Such techniques converging with the advances in software to process and model from coordinate points are classified in the category of digital shape sampling and processing, or DSSP. The technology underlying DSSP uses lasers, or structured light, to calculate the position of given points; the result of the scan is typically a pointcloud consisting of millions of xyz coordinate points representing the shape and the geometry of the scanned object. The process is very fast and can scan entire object shapes in just a few minutes, with good accuracy that can be used in most metrology applications.

Traditional Measurement Process

The current traditional measurement process, performed with a CMM for example, can be summarized in the following steps as discussed, presented and formalized at the International Metrology Interoperability Summit, (March 28th-30th, 2006) organized by NIST.

- Product definition
  - Create a part geometry
  - Define features & tolerance
    - Output is a 3D CAD model with complete GD&T information
- Measurement process definition
  - Identify resource(s)
  - Define information for setup
  - Define information on sensors
  - Identify characteristics to measure (GD&T or Dimensional Tolerances)
  - Generate inspection plan
    - Output is an inspection plan (text document or similar)
    - In case of a programmable CMM, an inspection program is also generated
- Measurement process execution
  - Load part on inspection device
  - Execute inspection plan
  - In case of a programmable CMM, a program is executed
  - Sensor collects data
    - Output is an XYZ coordinate of the inspected features
- Analysis & Reporting
  - Retrieve actual points
  - Analyze characteristics
  - Determine pass/fail
  - Generate Measurement report
  - In case of multiple inspections, generate statistical analysis
    - Output is a measurement report
    - In case of statistical analysis, output is an SPC report

The above steps are summarized in the workflow diagram in figure 1.

Although the number of key characteristics to be measured typically varies, this workflow is based on three main steps: a) identifying the key characteristics of the part to be measured; b) measuring them; and c) providing an analysis report of the resultant data.

"First article inspection" is an inspection of all the dimensions that can be determined on a drawing. It applies typically at the beginning of the production and the objective is to validate the repeatability of the process to produce the same part over and over. It applies to casting, moulding, stamping and machining. The measurement process used requires a significant investment in the number of times to take measurements. By being so comprehensive, it is inevitably very expensive.

Conversely, during regular production, which is geared to monitor the process and to validate the main key charac-

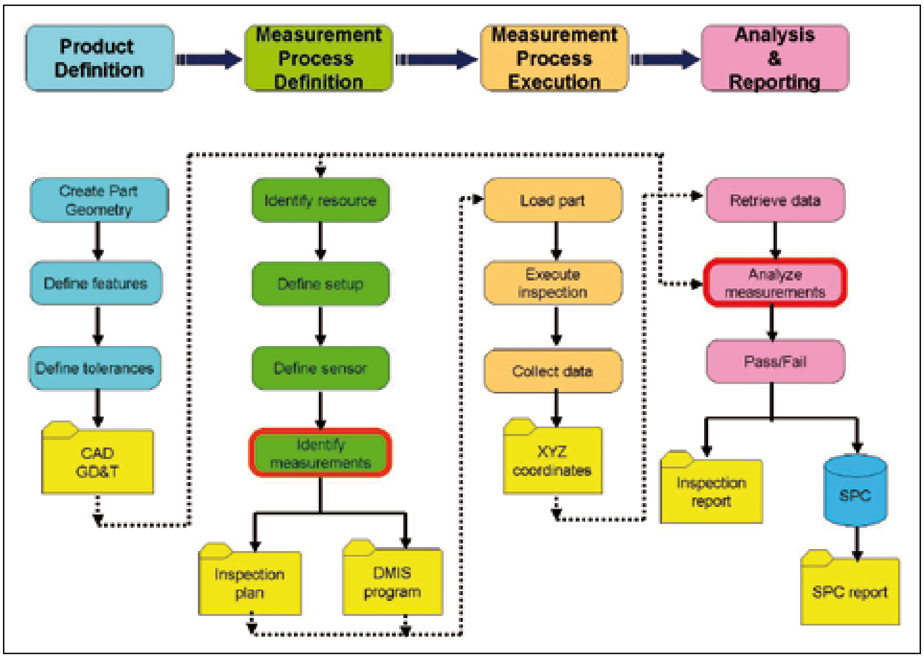


Fig. 2: Identify characteristics to be measured and analysed

teristics, fewer characteristics are inspected.

In both cases the measurement process is strongly driven by the identification of the characteristics to be measured and analyzed, as shown in the diagram in figure 2.

On the processes of measuring key characteristics, several issues may be studied.

For an inspection plan from which all possible key characteristics are measured, the following questions may be raised:

1. Why spend a long time on a CMM inspecting characteristics that might be within the design tolerances?
2. Why spend a long time analyzing all the inspection data to determine which characteristic is in, and out, of tolerance?
3. How can the inspection time be accelerated while measuring the entire object?

For an inspection plan from which a subset of key characteristics is measured, the following questions may be raised:

1. How can it be determined which characteristics have to be measured and which do not?
2. What is the result if some of the characteristics that are out of tolerance are not in the inspection plan?
3. How can characteristics that are out of tolerances be related to a wrong alignment?

A Paradigm Shift

Digital shape sampling and processing (DSSP) offers the capability to capture the entire shape of an object very quickly and accurately. This capability can currently be used during the measurement process to dramatically reduce time to collect dimensional data of an entire object (reduction up to 95 %), and to analyze the geometry of the object compared against nominal CAD geometry. Even though millions of points are captured to fully and accurately describe the shape of the object, the process only takes a few minutes.

A quick, 3D comparison of the captured shape against the nominal CAD geometry is performed and displayed on a computer screen using colour maps, such as the turbine blade shown in figure 3.

It becomes quite obvious to an engineer that the areas whose colour departs from the green are areas where the actual geometry departs from the nominal geometry. The darker the red, the further the deviation from the nominal – in terms of positive, and therefore more material – thus resulting in a wider blade. In terms of the opposite: the darker the blue indicated, the further the deviation from the nominal geometry – in terms of negative, and therefore less material – thus resulting in a thinner blade. The above analysis can easily be achieved in a fairly expedient manner (typically under 30 minutes); including: setup, scanning and analysis.

From the first analysis of comparing the captured turbine blade shape described by millions of points, further analysis can follow such as:

- GD&T (geometrical dimensioning & tolerancing) analysis to locate the deviation from a datum reference frame
- thickness analysis to locate critical thin walls, or
- airfoil analysis to analyze the main characteristics of the airfoil.

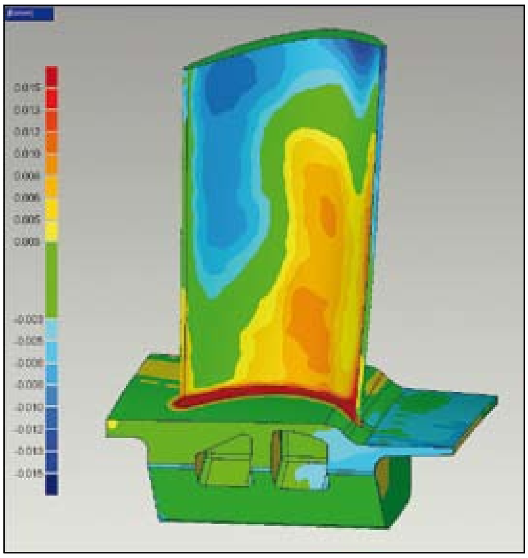


Fig. 3: Deviation colour map of a turbine blade

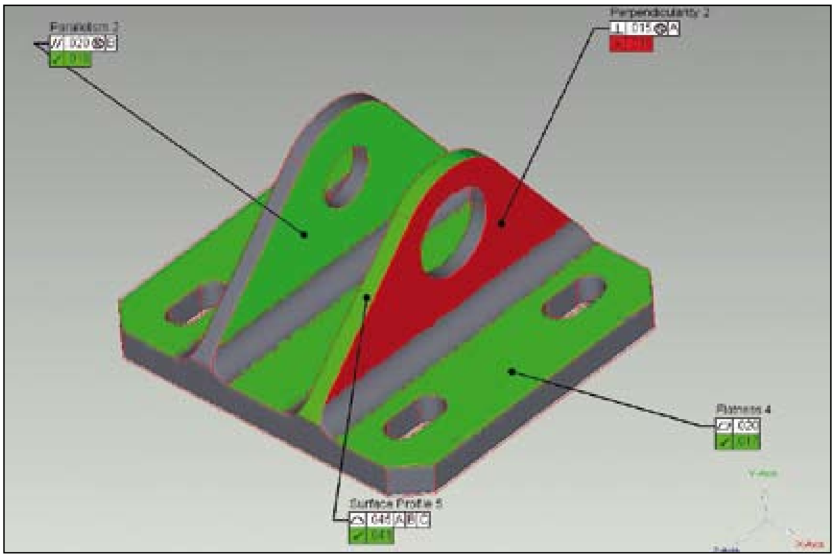


Fig. 4: Graphical representation of measurement data

The investigation and analysis is therefore focused on only the areas that deviate the most from the nominal geometry. This then minimizes unnecessary time and resources applied to measuring and analyzing areas that are obviously within tolerance to the desired nominal geometry.

With this new method, subsequent measurement and analysis of a part can focus primarily on the characteristics that are out of tolerance. Measuring coordinates and characteristics in a predefined and preplanned CMM program for measurements that are in tolerance is no longer necessary. Eliminating the unnecessary saves time and increases productivity.

Fig. 5: 2D sectioning and dimensioning

Turning Data into Information

Another major advantage offered by the DSSP technique is that it helps engineers to quickly interpret measurement data and shift from data collection to information analysis.

Using CMMs, hundred of points are collected which typically results in a list of nominal coordinates (x,y,z) and actual measurements (x1,y1,z1). Data in this form must then be processed, grouped and graphically represented so that engineers can quickly determine if a part passes or fails the dimensional inspection (fig. 4).

Taking it one step further, analysis of the resulting inspection data can drive change and process improvement. From information of inspection reports for failed parts, analysts can determine what are the causes of the out-of-tolerance measurements and, more important, what corrective actions are necessary to restore the process to producing parts in tolerance?

Using traditional inspection data, stored in databases and spreadsheets as numbers in tables and records, engineers spend hours, days, and sometimes weeks retrieving and massaging that data, to understand and compare it with CAD data and then documenting the analysis using tools such as Microsoft Word or Microsoft PowerPoint.

The time it takes from detection (of the process fault) to correction (of the process) is critical as the stopping of production is very expensive.

By capturing the full shape of the object and generating graphical reports that are easy to interpret, DSSP enables engineers to quickly focus on the manufacturing issues – providing information to the decision-maker at the right time, in the right format and rich in content rather than as large, useless amounts of data. In addition, colour maps of 3D deviation, GD&T analysis, more traditional 3D dimensioning and wall thickness analysis can be combined with 2D sectioning and dimensioning to more easily correlate with blue-printing and ballooning (fig. 5).

The inherent nature of DSSP producing digital and graphical data, easily and automatically compared to CAD data, eliminates the manual data-processing step and minimizes the time it takes from detection (of the process fault) to correction (of the process).

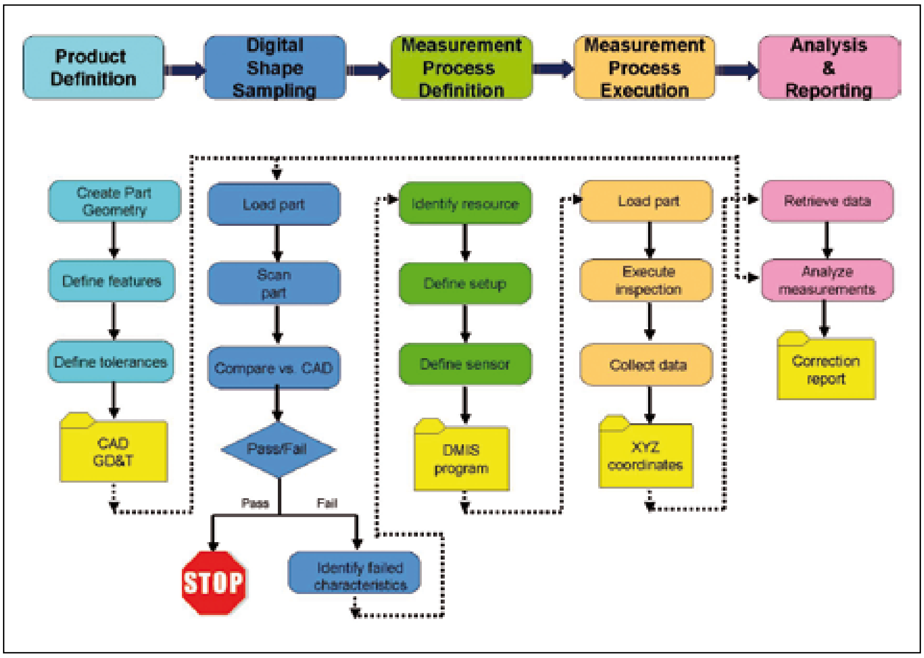


Fig. 6: New DSSP-based inspection workflow diagram

How DSSP Can Complement CMMs

Thus far, three major points have been introduced in this paper:

1. Traditional measurement techniques that are CMM-dependent are based on a workflow that identifies the features to inspect and analyze, regardless of whether or not they are within or without tolerance.
2. DSSP techniques can capture shapes of objects very quickly, identifying the critical dimensional areas.
3. DSSP reporting provides valuable, interpretive information to the decision maker, rather than bare, unintelligible data.

How can modern measurement techniques take advantage of these three points; merging them into an efficient, faster and economical measurement process?

The measurement process needs to change to take advantage of the faster

DSSP process as well as more precise, and therefore accurate, CMMs.

The selection of the features to be measured has to be different. Rather than measuring all the characteristics, the new process needs to measure and analyze only the characteristics that are needed; i.e. the critical measurements that are out of tolerance. The logical concept is predicated not on spending time and money in measuring what is already known to be within given tolerances; but instead, focusing only on what is known to be out of specification and needs to be corrected (either changing the process or re-machining the part).

In this approach, the steps are rearranged as follows.

- Product definition (unchanged)
  - Create a part geometry
  - Define features & tolerance
    - Output is a 3D CAD model with complete GD&T information
- Object shape capturing (DSSP)
  - Scan the part
  - Compare against nominal
  - Identify failed characteristics
  - Generate first analysis report
- CMM Measurement process definition
  - Identify resource(s)
  - Define information for setup
  - Define information on sensors
    - Output is a shorter inspection plan (text document or similar) focused on failed characteristics only
    - In case of a programmable CMM, an inspection program is also generated
- Measurement process execution
  - Load part on inspection device
  - Execute the inspection
  - Sensor collects data
    - Output is an XYZ coordinate of the inspected features
- Analysis & Reporting
  - Retrieve actual points
  - Analyze characteristics
  - Generate Measurement report
  - Determine corrective actions

The above steps are summarized in the workflow in figure 6.

Summary

A new measurement process, based on DSSP technology, is complementing, improving and revolutionizing the traditional CMM-based measurement process.

Using laser-based and/or white-light technology, the measurement process, while being much faster, also provides a more complete description of the shape. Out-of-tolerance areas are graphically displayed with deviation colour mapping, making very quick and easy the possible identification of critical out-of-tolerance areas. Only for this critical area is a more in-depth inspection process required along with proper inspection planning.

The paradigm shift in inspection planning and execution provided by DSSP technology allows customers to measure what is really dimensionally critical, saving time and money not inspecting what is either in tolerance or not critical.

Author
Alberto F. Griffa,
Business Development Manager

Geomagic, Inc., Research Triangle Park, NC, USA
Tel.: +1/800/691-1839
Fax: +1/800/251-5551.
agriffa@geomagic.com
www.geomagic.com