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In-line Metrology Station with Reorientation for Error Separation

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Abstract

This disclosure describes an in-line metrology station designed to separate measurement errors originating from a part from those originating from its supporting fixture. The system employs a reorientation mechanism to present the part-fixture assembly for measurement in at least two distinct orientations. A data processing unit then applies arithmetic calculations to the multiple measurement datasets to mathematically isolate the contributions of the part's geometry from any systematic deviations introduced by the fixture. This approach mitigates the misattribution of fixture-induced measurement deviations to the manufactured part, enabling targeted intervention for fixture service or part rejection.

1. Technical Field

[0001] The technical field is automated industrial metrology and inspection, specifically targeting in-line measurement systems used for quality control of manufactured components.

2. Technical Context

[0002] In automated manufacturing environments, components are frequently measured while held in a fixture. This fixture provides datum surfaces or clamping forces to present the component in a stable, repeatable position to a metrology unit. A fundamental challenge in such systems is distinguishing between geometric deviations inherent to the manufactured part and deviations introduced by the fixture itself. A misaligned, worn, or contaminated fixture can cause a perfectly good part to appear out of specification, leading to unnecessary rejection, rework, or process adjustments. Conversely, a faulty part might pass inspection if the fixture error compensates for the part error. Conventional in-line gauges often treat the part-fixture assembly as a single entity, making it impossible to ascertain the true source of a measured deviation. This leads to reduced measurement confidence and increased operational cost due to false positives or negatives.

3. System Overview

[0003] The disclosed in-line metrology station provides a mechanism for distinguishing part-related geometric deviations from fixture-related deviations. As shown in FIG. 1, the system comprises a Part Handling unit (10), a Fixture (12) that holds the component, a Reorientation mechanism (14), a Metrology Unit (16), a Control System (18), and a Data Processing unit (20). Parts are conveyed into the station, loaded onto the Fixture (12), and presented to the Metrology Unit (16) for an initial measurement in a first orientation. The Reorientation mechanism (14) then precisely changes the orientation of the part-fixture assembly relative to the Metrology Unit (16). A second measurement is performed in this new orientation. The

Data Processing unit (20) receives both sets of measurement data and applies a set of arithmetic operations to separate the geometric deviations of the part from those attributable to the Fixture (12). The Control System (18) manages the sequence of operations, data acquisition, and provides outputs for decision-making regarding part disposition or fixture maintenance.

4. Components

[0004] The primary components of the in-line metrology station are:

[0005]

- **Part Handling Unit (10):** This unit is responsible for the automated conveyance of parts into and out of the metrology station. It may include conveyors, robotic pick-and-place mechanisms, or chutes. Its function is to reliably deliver parts to the Fixture (12) and to remove them after inspection.
- **Fixture (12):** This component is designed to hold the part in a stable and repeatable manner during the measurement process. Fixtures can range from simple pallets or jigs to complex clamping mechanisms. The Fixture (12) itself may have inherent geometric deviations or positional errors relative to the metrology system's coordinate frame.
- **Reorientation Mechanism (14):** As depicted in FIG. 2, this mechanism precisely alters the spatial orientation of the part-fixture assembly. This may be a rotary table (26) that rotates the Fixture (12) and part (24) about an axis, a robotic gripper arm (28) that picks and re-places the part or fixture, or a kinematic coupling that allows for repeatable disengagement and re-engagement in a new configuration. The reorientation must be precise and repeatable to allow for accurate data correlation. A typical rotation angle might be 90 degrees or 180 degrees, but other angles are feasible depending on the part geometry and measurement requirements.
- **Metrology Unit (16):** This unit performs the actual geometric measurement of the part (24) while it is held in the Fixture (12). It can be a non-contact system such as an optical scanner (e.g., laser triangulation, structured light, machine vision) or a contact system such as a coordinate measuring machine (CMM) probe. The unit must be capable of generating a measurement dataset that accurately represents the part's geometry relative to a defined coordinate system, often aligned with the Fixture (12) or the station itself.
- **Control System (18):** This comprises a programmable logic controller (PLC) or industrial PC that orchestrates the operation of all other components. It manages part flow, triggers measurements, controls the Reorientation mechanism (14), and communicates with the Data Processing unit (20). It also handles error states and safety interlocks.
- **Data Processing Unit (20):** This unit, often an industrial computer, receives raw measurement data from the Metrology Unit (16). As shown in FIG. 3, its primary function is to execute the algorithms necessary to separate part errors from fixture errors. This involves data registration, transformation, and arithmetic decomposition of measured deviations. It outputs calculated part deviations, fixture deviations, and pass/fail/service decisions.

5. Operation

[0006] The operation of the in-line metrology station proceeds through several stages for each part:

[0007]

- **Part Loading and Initial Measurement:** A part is delivered by the Part Handling unit (10) and precisely loaded onto the Fixture (12). The Fixture (12) then positions the part within the measurement volume of the Metrology Unit (16) in a first, known orientation. The Metrology Unit (16) acquires a complete set of geometric data (Measurement 1 (30)) for the part-fixture assembly. This data is transmitted to the Data Processing unit (20).
- **Reorientation:** Once the first measurement is complete, the Reorientation mechanism (14) activates. It precisely repositions the part-fixture assembly into a second, distinct orientation relative to the Metrology Unit (16). This reorientation might involve a rotation, translation, or a combination thereof, but its exact transformation must be known or accurately inferable. For instance, a 180-degree rotation allows features initially facing the Metrology Unit (16) to be presented from an opposite direction.
- **Second Measurement:** With the part-fixture assembly in the reoriented position, the Metrology Unit (16) acquires a second complete set of geometric data (Measurement 2 (32)). This data is also transmitted to the Data Processing unit (20).
- **Error Separation:** The Data Processing unit (20) receives both Measurement 1 (30) and Measurement 2 (32). An Alignment Algorithm (34) first registers the two datasets to a common coordinate system, accounting for the known reorientation transformation. A Difference Calculation (36) is then performed, typically by comparing corresponding points or features between the two measurements. For example, if a point on the part is measured as `P1_meas` in the first orientation and `P2_meas` in the second, and the fixture point is `F1_meas` and `F2_meas`, the algorithms can leverage the known reorientation to distinguish systematic fixture errors from random part variations. For a specific feature, if `D1` is the measured deviation in the first orientation and `D2` is the measured deviation in the second orientation (after transformation to a common reference frame), then the part error `Ep` and fixture error `Ef` can be approximated by:

[0008] `Ep = (D1 + D2) / 2` `Ef = (D1 - D2) / 2` This assumes the fixture error has a consistent effect on the part's position relative to the measurement frame, while the part's geometry remains intrinsic. More complex algorithms may apply statistical analysis or geometric decomposition methods (Error Decomposition (38)) across multiple points or surfaces.

[0009]

- **Decision and Output:** Based on the separated part error `Ep` and fixture error `Ef`, the Decision Logic (40) determines the disposition of the part. If `Ep` exceeds a defined tolerance, the part is flagged for rejection or rework. If `Ef` exceeds a fixture drift threshold, the Control System (18) triggers an alert for fixture service or recalibration. The part is then unloaded by the Part Handling unit (10).
- **Fault/Interruption Handling:** In case of a measurement error, part misload, or system malfunction, the Control System (18) halts operations, alerts an operator, and records the fault. Depending on the nature of the fault, the part may be held in place, ejected to a reject bin, or returned to a previous station.

6. Example Embodiments

[0010] **Embodiment 1** This embodiment utilizes a single, dedicated metrology station with a rotary table as the Reorientation mechanism (14). The Fixture (12) is permanently mounted to the rotary table (26). Parts are loaded onto the Fixture (12) by a pick-and-place robot from an upstream conveyor. The Metrology Unit (16) is a fixed-mount laser scanner that captures a dense point cloud from multiple angles. After the first scan, the rotary table (26) rotates the fixture and part by 180 degrees about a vertical axis. A second scan is performed. The Data Processing unit (20) applies a rigid body registration algorithm to align the two point clouds, then calculates point-to-surface deviations. The deviation vectors are analyzed to decompose fixture offset from part form error.

[0011] **Embodiment 2** In this configuration, the Reorientation mechanism (14) is a robotic arm equipped with a specialized gripper (28). The Fixture (12) is a simple nest on a transfer plate. After an initial measurement by a multi-probe CMM (Metrology Unit (16)), the robotic arm (28) precisely lifts the part (24) from the Fixture (12), rotates it by 90 degrees about an axis parallel to the part's main dimension, and places it back onto the same Fixture (12). This allows for measurement of features that were previously obscured or presented at a suboptimal angle. The CMM then performs a second measurement. The Data Processing unit (20) uses the known robotic transformation to align the two datasets and calculate the separate errors. This embodiment is suitable for parts requiring access to multiple faces without repositioning the entire fixture.

[0012] **Embodiment 3** This embodiment is integrated into a larger assembly line where multiple parts are processed on a continuous conveyor system. Each part is held in its own pallet-style Fixture (12). The Metrology Unit (16) consists of two optical profilers positioned at different points along the conveyor line. The Reorientation mechanism (14) is an automated indexing unit that lifts each pallet, rotates it by 180 degrees, and places it back on the conveyor between the two profilers. The first profiler measures the part in its initial orientation. The part then passes through the indexing unit, is reoriented, and is measured by the second profiler. The Data Processing unit (20) correlates the measurements from the two profilers to perform the error separation, factoring in any known offset between the two profiler systems.

7. Alternative Configurations

[0013] The Metrology Unit (16) can be implemented using various technologies beyond laser scanning or CMM probes. These include structured light projection systems, industrial computed tomography (CT) scanners, ultrasonic testing arrays, or vision systems employing multiple cameras and photogrammetry techniques. The choice depends on the required accuracy, material properties, and feature complexity. The Reorientation mechanism (14) could also be a dual-fixture system where a part is transferred from a first fixture to an identical, but physically rotated, second fixture for the second measurement. This might be advantageous for very large or heavy parts where rotating the entire fixture is impractical. Furthermore, instead of reorienting the part, the Metrology Unit (16) itself could be reoriented around a stationary part and fixture, for example, by mounting it on a robotic arm or a gantry system capable of moving to multiple measurement positions.

8. Parameter Variations

Parameter	Range	Effect of Moving Towards Lower End	Effect of Moving Towards Upper End
Measurement Cycle Time	5 to 60 seconds	Increases throughput, may reduce measurement density/accuracy.	Decreases throughput, allows higher measurement density/ accuracy.

Parameter	Range	Effect of Moving Towards Lower End	Effect of Moving Towards Upper End
Reorientation Angle	90 to 180 degrees	May provide less distinct views, potentially ambiguous error sep.	Provides maximum view difference, clearer error separation.
Fixture Error Drift Threshold	0.005 to 0.05 mm	Triggers fixture service alerts more frequently, higher uptime.	Triggers fixture service alerts less frequently, higher risk of bad parts.
Number of Reorientations	1 to 3	Faster cycle, simpler algorithm, less comprehensive error mapping.	Slower cycle, more complex algorithm, more robust error mapping.
Part Weight (for handling)	0.1 to 50 kg	Simpler, faster handling mechanisms, lower power consumption.	Requires robust, slower handling, higher power, complex robotics.
Metrology Resolution	0.001 to 0.05 mm	Higher precision, detects finer defects, slower acquisition.	Lower precision, faster acquisition, may miss subtle defects.

9. Additional Implementations

[0015] The separated part and fixture error data can be integrated into a larger manufacturing execution system (MES) or statistical process control (SPC) system. By trending the fixture error `Ef` over time, the system can predictively schedule maintenance for specific fixtures, rather than relying on time-based schedules or reactive failure. This predictive maintenance capability optimizes fixture utilization and reduces unscheduled downtime. The collected part error `Ep` can be fed back to upstream manufacturing processes, enabling real-time adjustments to machining parameters, assembly forces, or material flow to prevent the production of further non-conforming parts. This immediate feedback loop contributes to adaptive manufacturing control. Furthermore, the system can be used not only for production parts but also for periodic calibration and validation of the fixtures themselves, providing an in-situ method to verify fixture integrity against known master parts.

10. Figures

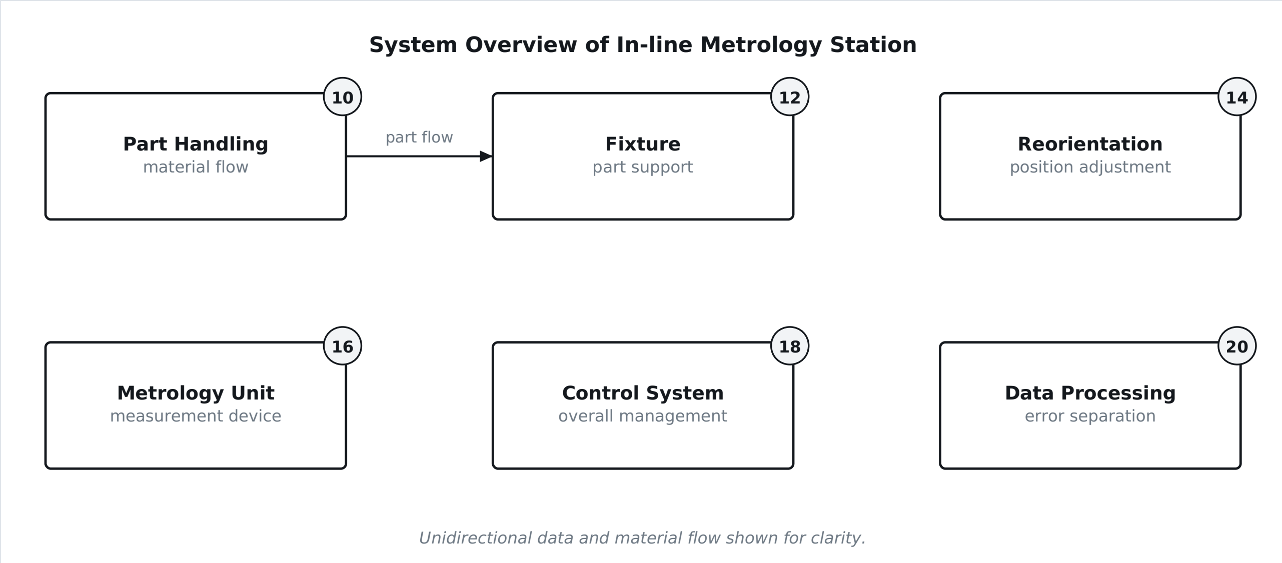

FIG. 1 A block diagram illustrating the primary functional units and data flow within the in-line metrology station. PNG

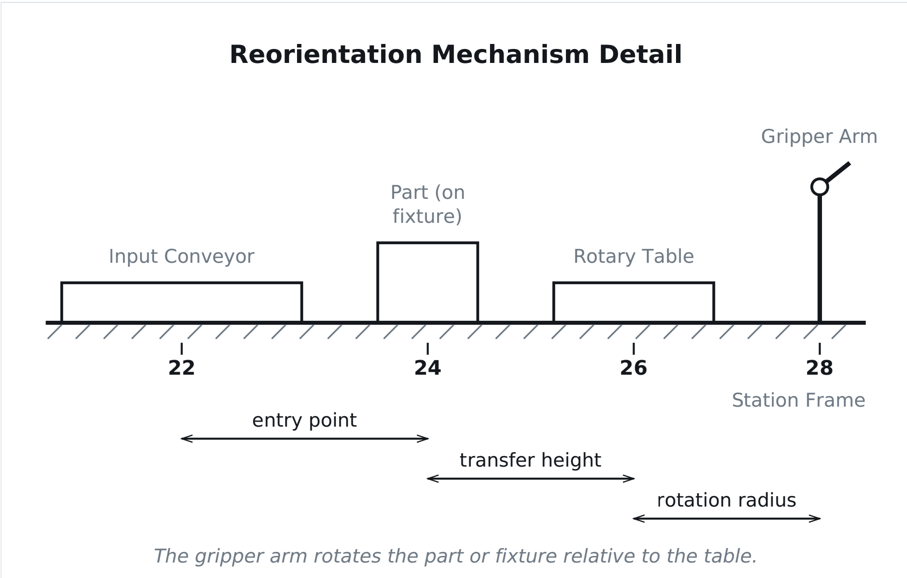

FIG. 2 An elevation view detailing a reorientation mechanism featuring a rotary table and part gripper. PNG

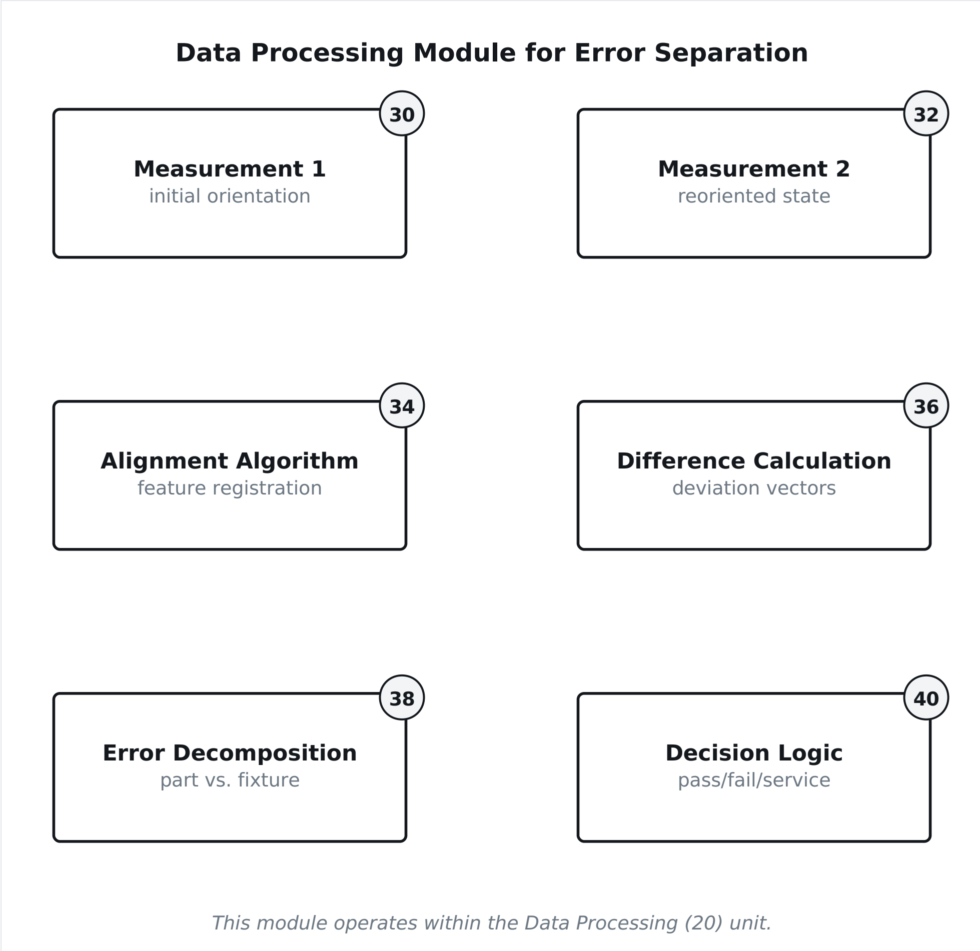

FIG. 3 A block diagram illustrating the steps within the data processing unit to separate part and fixture errors.
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