SmartProcess

Smart Process Planning for Inspection

ELECOMP Capstone Design Project 2021-2022

Sponsoring Company:

Hexagon Manufacturing Intelligence
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Company Overview:

Hexagon Manufacturing Intelligence, formerly known as Hexagon Metrology, is the world leader in quality control solutions for manufacturing. Solutions include hardware, software, and services in a broad portfolio of products which include stationary coordinate measuring machines (CMMs) for the automated inspection of manufactured components. Coordinate measuring machines are essentially large precision positioning systems that carry accurate sensors in the x, y, z directions for the dimensional inspection of manufactured components. These machines have specialized controllers and firmware and are programmable through dedicated software. These systems are produced here in Rhode Island at Hexagon's Quonset facility for North America.

In addition to manufacturing CMMs and providing supporting software and services for inspection, Hexagon has also been more broadly entering the smart manufacturing space, providing intelligent systems, including custom automation cells and MES software solutions. MES software solutions such as Smart Factory (HxGN SFx) enable the merging of measurement data from the inspection process together with other data from all types of production assets for a more complete view of the manufacturing process. Together this 'big data' is stored in a cloud server so that it can be analyzed on demand from any location.

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Project Motivation:

Hexagon's Smart Factory (https://login.hexagonsfx.com/Account/Login) was initially developed to help improve operational efficiency of the inspection process for our customers. The current software can effectively monitor our existing measuring systems, known as coordinate measuring machines (CMMs) and calculate their overall equipment effectiveness (OEE); however, it is believed that the benefits of this solution can be greatly improved by monitoring the process of that system and not just the CMM asset itself. A complete understanding of the process requires that we can monitor all peripheral hardware and software through which there is either human or machine communication with the asset. It is believed that through the development of a complete model of the process surrounding our own CMM assets that we will be able to build similar models of other types of assets in the factory and a complete solution for the whole factory.

One specific pain point for operating a CMM, much like any machine tool, is knowing the frequency of retooling and setup times for different jobs. For a CMM, a probe stylus is analogous to a cutting tool, and its frequency and manner of use determines how often that stylus must be requalified for accuracy. Likewise, changing jobs on a CMM is like changing jobs on any type of machine tool in that it often requires different fixture setups or work holding methods. In practice, most manufacturing operations try to limit job changes or setup changes on machine tools to keep production moving as smoothly and efficiently as possible. For this reason, many manufacturers will have machine tools which are dedicated for specific jobs, or else a limited number of similar jobs, in order to minimize changeover time between jobs. On the contrary, for CMMs this is not the case. CMMs are expensive assets requiring specialized skillsets to use them, and so tend to be a limited resource in the factory. CMMs are also designed to be flexible with the intention of serving the inspection needs of all types of components, on demand, from any operation within the factory. The problem with this is that there is inherently a great deal of inefficiency due to constant changeover of different setups and different probe styli required for different jobs. Consequently, due to CMMs being a limited resource and subject to these inefficiencies, there is often a significant backlog of work. Quality Managers constantly struggle to coordinate and schedule the use of their CMM assets to minimize such backlog, but their decisions are only as good as the information they have to support them.

Project Details:

This project will focus on the collection of data for the inspection process using a CMM and the merging and analysis of that data for process optimization. Data collection will require running a special data collector script from within the PC-DMIS measuring software and Smart Factory (SFx software), both of which will be provided. The analysis will include the identification of key parameters required for process optimization, with emphasis on probe stylus usage patterns and job scheduling to minimize downtime due to fixture changeover. The goal of the project is to develop a method or algorithm that can be used to determine optimal stylus use for a variety of changing jobs in a work schedule, optimal timing for probe styli qualification in a work schedule, optimal scheduling of jobs in order to minimize changeover time and probe changing time. An A.I. model for optimization may be applied in this case, although a direct solution may also be acceptable if one can be found. It may also be possible to have different solutions for optimizing different sets of data, depending on what is being measured in the process, for example.

The Global™ CMM, which is available in the FCAE's Hexagon Metrology Lab includes PC-DMIS measurement software and a probe changer rack on which multiple styli can be arranged to support different types of inspection jobs. This may be used as a test asset from which multiple inspection jobs can be run and used for data collection. For this purpose, a few simple measuring programs using several test parts will be required along with holding fixtures and designated probe styli. These simple programs will be written in PC-DMIS' native language for the CMM and will give the participating students better insight into the operation of the equipment and typical process observed by manufacturers. Additionally, a second CMM will also be available to run with an automated part loading system. This system includes a UR robot at the Hexagon factory located at Quonset Point. Both systems will be able to run the same inspection jobs and be remotely monitored together through Smart Factory software. The inspection process will be essentially the same between the two system with the exception that the one at Hexagon is automated and the one at URI will require that inspection jobs are manually loaded. The purpose of having these two systems to collect data is two-fold: first that we can collect more real data with two systems and secondly that we will be able to see obvious differences in performance

(OEE) between the two systems. An important conclusion regarding the proposed optimization solution will be its validation when comparing different systems in different operating environments. It is expected that the proposed optimization should apply to both systems although the benefits of that optimization may be less for the more fully automated process, for example.

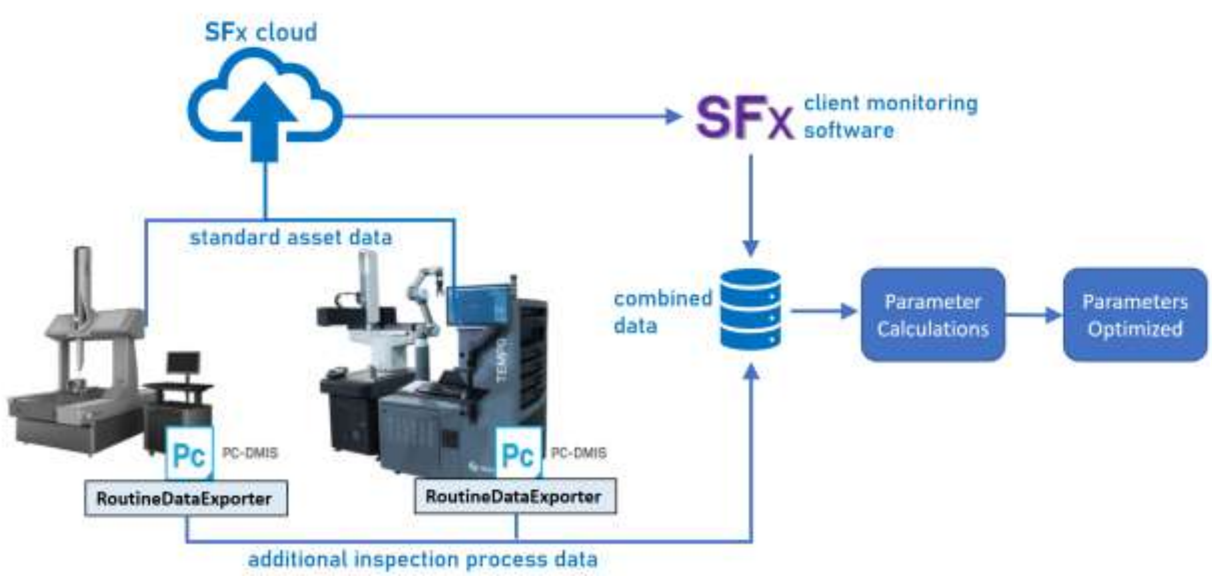
Overall system concept:

The overall system will include the following key elements:

- Two measuring system assets with PC-DMIS measuring software
- Cloud server from which existing asset usage data can be monitored and retrieved through SFx client software
- Data extraction script named RoutineDataExporter through which additional process data can be collected from the PC-DMIS software
- Aggregation of the data from separate sources into a single database (combined data)
- Calculation of key parameters from the raw data desired for optimization
- Optimization model or algorithm

Items *highlighted* above are areas of new development and the focus of this project effort.

Block Diagram:



The project may be broken into the following phases (ideally each semester) with key tasks:

PHASE 1:

- Onboarding of the URI lab asset with SFx Connector
- Implementing three (3) measuring routines in PC-DMIS using several different probe styli from a tool changer
- Verify the collection of raw data using both the RoutineDataExporter and SFx client software

PHASE 2:

- Calculate the key parameters needed for optimization and combine into a common database from the separate sources
    - Some examples may include:
        - Individual setup and breakdown time for each inspection job
        - Changeover time between jobs having specific types of fixtures
        - Probe stylus usage frequency
        - Probe stylus environmental sensitivity
- Maximize operational efficiency (OEE) of the systems by using the parameters to optimize:

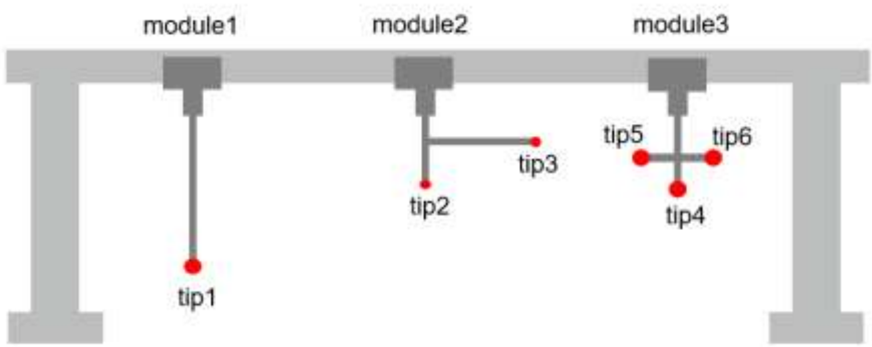
    (1) probe styli usage (elimination of redundant tool changing)
    (2) scheduling (order) of jobs for a known work backlog
    (3) probe qualification schedule within a predefined work schedule

Problem Example:

EXAMPLE 1:

Theoretical example whereby a customer has the following:

- (3) measuring routines (prg1.prg, prg2.prg, prg3.prg)
- (6) qualified probes (tip1, tip2, tip3, tip4, tip5, tip6)
- (3) module tool rack (mod1, mod2, mod3)



Styli module arrangements:

Routine	Tips used	Features Measured			Tip Use counts
Prg.1	Mod1: tip1 Mod3: tip4, tip6	Feat1 (tip1) Feat2 (tip1)	Feat3 (tip4) Feat4 (tip4) Feat5 (tip4)	Feat6 (tip6)	tip1: 2 tip4: 3 tip6: 1
Prg.2	Mod1: tip1 Mod2: tip2, tip3	Feat1 (tip1) Feat2 (tip1) Feat3 (tip1) Feat4 (tip1)	Feat5 (tip2) Feat6 (tip2) Feat7 (tip2) Feat8 (tip2)	Feat9 (tip3) Feat10 (tip3)	tip1: 4 tip2: 4 tip3: 2
Prg.3	Mod3:tip4, tip5, tip6	Feat1 (tip4)	Feat1 (tip5) Feat1 (tip5) Feat1 (tip5)	Feat1 (tip6) Feat1 (tip6) Feat1 (tip6)	tip4: 1 tip5: 3 tip6: 3

Hypothetical (non-optimized) schedule for a weekly workplan:

Time of day	S	M	T	W	T	F	S
8:00		qualify probes	qualify all probes	qualify all probes	qualify all probes	qualify all probes	qualify all probes
9:00		prg.1	prg.2	prg.3	prg.2	prg.2	prg.2
10:00		prg.1	prg.2	prg.3	prg.2	prg.2	prg.2
11:00		prg.1	prg.2	prg.3	prg.3	prg.2	prg.2
12:00		prg.1	prg.2	prg.3	prg.3	prg.1	prg.2
13:00		prg.1	prg.2	prg.3	prg.3	prg.1	prg.2
14:00		prg.1	prg.2	prg.3	prg.3	prg.1	prg.2
15:00		prg.2	prg.2	prg.3	prg.3	prg.1	prg.2
16:00		prg.2	prg.2	prg.3	prg.1	prg.1	prg.2
17:00		prg.2	prg.2	prg.2	prg.1	prg.1	prg.2
		prg.2	prg.2	prg.2	prg.1	prg.2	prg.2
		prg.2	prg.2	prg.2	prg.1	prg.2	prg.2
		prg.2	prg.2	prg.2	prg.1	prg.2	prg.2
		prg.2	prg.2	prg.2	prg.1	prg.2	prg.2

Work backlog:

Job 1: including (6) parts for item #0001 (prg.1)

Job 2: including (20) parts for item #0002 (prg.2)

Job 3: including (8) parts for item #0003 (prg.3)

Job 4: including (7) parts for item #0002 (prg.2)

Job 5: including (5) parts for item #0003 (prg.3)

Job 6: including (6) parts for item #0001 (prg.1)

Job 7: including (6) parts for item #0001 (prg.1)

Job 8: including (3) parts for item #0003 (prg.3)

Job 9: including (6) parts for item #0001 (prg.1)

Job 10: including (17) parts for item #0002 (prg.2)

Anticipated Best Outcome:

The best outcome is to have a software solution that uses the available raw data collected by both SFx and the added RoutineDataExporter that is able to do the following:

(1) Identify probe use redundancy within a group of measuring routines and recommend substitutions to remove such redundancy, which can be validated through SFx through either OEE gains and/or time savings.
(2) Determine the ideal probe qualification frequency based on historical probe usage data, environmental influences (if any) and the optimal probe qualification time within a planned job schedule
(3) Identify patterns of down time caused by changeover between different types of jobs and other operational factors that are currently measurable.
(4) Optimization of the job schedule using derived downtimes due to fixture changeover/setups and any other factors which may be of influence, including human influence of changing operators for manually operated systems, for example.

Hardware Tasks:

- Hardware tasks include the setup and defining of probe styli clusters on the CMM tool rack as well as fixture design for the holding of various parts while being inspected by the CMM.

Firmware/Software/Computer Tasks:

- Download SFx software online and go through the onboarding process for a new asset, which is the Global CMM at URI's Hexagon Metrology Lab.
- Write unique measuring routines using PC-DMIS for several representative parts using the different probe styli clusters defined in Hardware. These routines should also include the measurement of several geometric features which result in a typical industry cycle time of at least 1 minute and not exceeding 5 minutes.
- Aggregate data from the different sources into a single database for analysis of measurable parameters

Software tool developed to recognize patterns in the data that may support the best outcome objectives. The software tool may implement any number of algorithms including ones developed using A.I.

Composition of Team:

2-3 Computer Engineers (CPE), 2-3 Industrial and Systems Engineers (ISE)

It is anticipated that one engineer might be best suited to do the CMM measurement routine programming, collection of data and calculation of key parameters using raw data sources and that another engineer, preferably with some subject matter background in industrial engineering, smart manufacturing, to apply known methods for OEE optimization. It is also possible that a senior, with a background in computational science, may have knowledge of A.I. algorithms which may be applicable in this case.

This project is a joint effort by both ELECOMP Capstone and Industrial and Systems Engineering Capstone programs. Work relevant to either field of study will be tasked to their respective students/team members.

Skills Required:

Engineering Skills Required or Recommended:

- Programming experience (preferably, with CNC or CMM machines)
- Knowledge of industrial metrology or measurement practices
- Manufacturing process planning and method of calculating OEE
- Optimizing complex systems using big data
- Database Design
- Data collection, aggregation, normalization, sanitization
- Experience with organizational datatypes like JSON
- Experience with Machine Learning (ML) and artificial intelligence (A.I)

Anticipated Best Outcome's Impact on Company's Business, and Economic Impact

The impact of meeting the stated objectives is that we will be able to implement as high value-added features in the next release of SFx Smart Factory software and greatly increase the volume of sales of that solution within our existing customer base. The long-term impact of having a more intelligent MES solution for CMMs within the measurement process is that we can leverage that to expand similar capabilities more broadly to other assets and other areas in manufacturing. It is believed that CMMs and the inspection process represent a particularly challenging problem in most operations due to their complexity and may in fact be the most difficult to optimize or make improvements to OEE. In other words, if we can solve these problems for CMMs we can solve them for other assets as well.

Broader Implications of the Best Outcome on the Company's Industry:

The broader implications of having such a software solution for manufacturing is enormous in that there is an enormous opportunity for savings by just being able to improve the way existing assets are used. When comparing this to adding or replacing equipment to achieve the same gains in productivity the cost may be only a fraction. The impact on the Company's industry will be greater awareness to manufacturers that the easiest way to propel your business to success in the next century and is to implement intelligent software systems. This is how you realize Industry 4.0.