Available online at www.sciencedirect.com
ScienceDirect
Procedia CIRP 44 (2016) 138 – 143
www.elsevier.com/locate/procedia
6th CIRP Conference on Assembly Technologies and Systems (CATS)

An industrially validated CMM inspection process with sequence constraints

Raad Salman[a,*], Johan S. Carlson[a], Fredrik Ekstedt[a], Domenico Spensieri[a], Johan Torstensson[a], Rikard Söderberg[b]

[a]*Fraunhofer-Chalmers Centre, Chalmers Science Park, SE-412 88 Göteborg, Sweden*
[b]*Wingquist Laboratory, Chalmers University of Technology, 412 96 Gothenburg, Sweden*

* Corresponding author. Raad Salman, Tel.: +46-739-837573; *E-mail address:* raad.salman@fcc.chalmers.se

Abstract

An efficient CMM inspection process implemented in industry gives significant productivity improvements. A key part of this improvement is the optimization of the inspection sequences. To ensure quality of the inspection the sequences are often constrained with respect to the order of the measurements. This gives rise to so called precedence constraints when modelling the inspection sequence as a variation of the travelling salesperson problem (TSP). Two heuristic solution approaches and a generic optimizing algorithm are considered. A generation based stochastic algorithm is found to reduce cycle time by as much as 12% in comparison to the currently used algorithm.

Keywords: CMM; inspection; automation; task sequences; precedence constraints; generalized travelling salesman problem; sequential ordering problem

1. Introduction

Many products such as car and truck bodies, engines, medical prosthesis, mobile phones, and lumbering equipment depend visually and functionally on its geometry. Since variation is inherent in all production processes, consistent efforts in styling, design, verification and production aiming at less geometrical variation in assembled products, is a key to shortening development time of new products, as well as for choosing an efficient and resource-economic production process. The activities aiming at controlling geometrical variation throughout the whole product realization process are called the geometry assurance process. Figure 1 shows a general model for product realization consisting of a concept phase, a verification phase and a production phase.

The geometry assurance process, as defined in [1], relies on inspection data in all phases. Product concepts are analyzed and optimized to withstand the effect of manufacturing variation and tested virtually against available production data often based on carry over type of inspection. In the verification and pre-production phase the product and the production system is physically tested and verified. Adjustments are made to both product and production system based on inspection data. In full production the focus is to control the process and to detect and correct errors by analyzing inspection data. These inspection data are often collected before, during and after important assembly steps. In this way, important assembly issues as part, fixture and joining errors can be detected and corrected in an efficient manner.

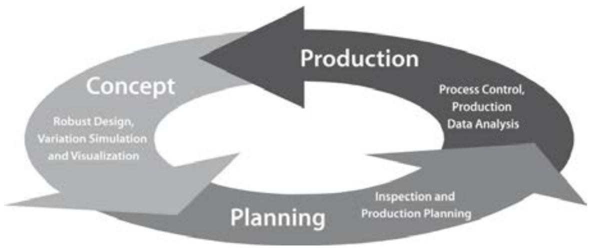

Fig. 1. A general model for product realization and the main activities of the geometry assurance process.

Therefore, the inspection preparation and measuring is an important activity and this paper presents an industrial validated closed loop from inspection preparation to automatic efficient off-line programming of automated measurement equipment. Then the focus is on improving the sequence optimization part of it by solving precedence constrained generalized travelling salesperson problem.

doi:10.1016/j.procir.2016.02.136

2. An Efficient Process for Inspection Preparation and Programming

The efficient inspection process implemented to support programming of automated inspection devices is built up by five main steps; (i) define the inspection task by breaking down product and process requirements to geometrical inspection features, e.g. a hole or a slot, on part and subassembly level (Figure 2), (ii) create parameterized inspection rules that define how a feature should be measured, i.e. number of points, distribution, coordinate system, and probe cones, (iii) perform feature accessibility analysis to find a set of probe configurations of minimum size that can reach all inspection points with collision free CMM configurations (Figure 3), (iv) plan by math based algorithms for motion planning and combinatorial optimization the collision free motions and sequence of the measurement equipment to visit each feature, and (v) generate the control code, e.g. DMIS to instruct the equipment to perform the actual measurement.

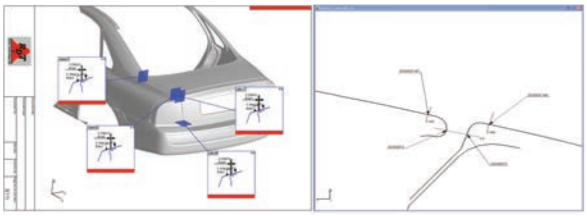

Fig. 2. An inspection task is defined by breaking down the product quality appearance requirement (right picture) on gap and flushes to boot and rear fender part inspection points (right picture).

This process has been industrially evaluated and used by e.g. Volvo Cars to program all automated inspection devices since 2011. The results show an improvement in inspection preparation time of 75% and productive increase in equipment utilization of 25%. The experience is also that the inspection preparation process becomes more structured and thereby reusable to a larger extent than previously.

2.1. Parameterized Inspection Rules

As mentioned, part of the process is to create parameterized inspection rules for the most commonly used inspection features in practice, i.e. surface point, edge point, circular hole, oval hole, rectangular hole, sphere, and cylinder [2,3]. The parameterization describes the inspection rule in terms of number of points, positions and probe configurations, and the allowed deviation from the ideal/default rule [4]. Today, it is common that the CMM embedded software contains the inspection rules and decides the motion patterns and sequence during feature inspection. However, the proposed approach with parameterized inspection features has four key advantages: (i) it makes the inspection preparation flexible, structured and repeatable, (ii) the same control code can be used with CMMs of different brands with more consistent results, (iii) the inspection sequence inside and between features can be optimized together to minimize cycle time, (iv) if the default inspection rule is not feasible due to collisions then the conflict can automatically be resolved by using the allowed deviation from the default rules. In Figure 4, as an example, the parameterized inspection rule for a circle is defined and illustrated.

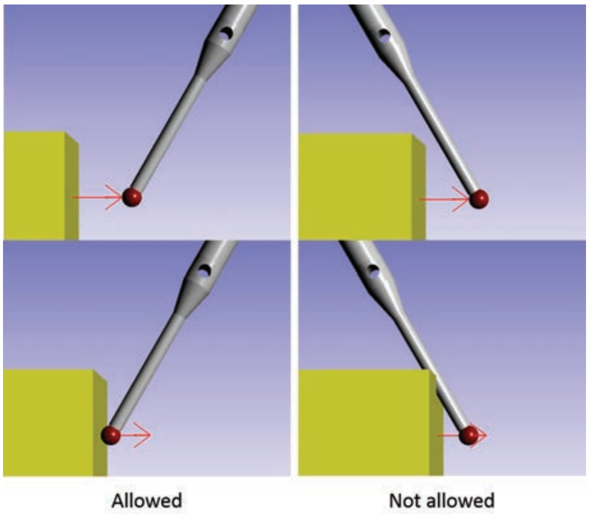

Fig. 3. Approachability illustrated; It should be possible to perform a linear motion along the inspection direction from a specified approach point and that the probe sphere/tip should make contact with the inspection point during that motion without any further collisions. The red arrow represents the normal of the inspection point.

Inspection Feature	Feature Definition	Inspection Rule
Circle	P: Position vector D: Diameter T: Thickness	t1: Measurement depth α1: Start angle (points on) plane α2: Start angle (points in) circle n1: #Points on plane n2: #Points in circle d1: Diameter on circle in plane

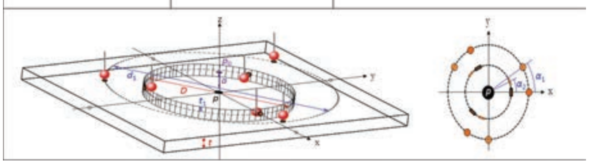

Fig. 4. A parameterized inspection rule of circle feature.

2.2. Automatic Path Planning

The next technology used is path planning where the collision free CMM motions are generated by automatically finding via points and probe reorientations between the inspection features [5,6,15]. Complete path planning algorithms, which always find a solution or determine that none exist, are of little industrial relevance since they are too slow. In fact, the complexity of the problem has proven to be PSPACE-hard for polyhedral object with polyhedral obstacles [7]. Therefore, sampling based techniques trading completeness for speed and simplicity is the choice. Common for these methods are the needs for efficient collision detection, nearest neighbor searching, graph searching and graph representation. The two most popular