Case-Based Reasoning Applied to Geometric Production Measurements

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ABSTRACT
Measurements from products are continuously collected to allow adjustments in the production line to certify a feasible product quality. Case-Based Reasoning is a promising methodology for this type of quality assurance. It allows product measurements and its related adjustments to the production line to be stored as cases in a Case-Based Reasoning system. The idea is to describe an event of adjustments based on deviations in geometric measurement points on a product and connect these measurements to their correlated adjustments done to the production line. Experience will implicitly be stored in each case in the form of uniquely weighted measurement points according to their positive influence on adjustments. Methods have been developed in order to find these positive correlations between measurements and adjustments by analysing a set of historical product measurement and their following adjustments. Each case saved in the case base will be "quality assured" according to this methods and only cases containing strong positive correlations will be used by the system. The correlations will be used to supply each case with its own set individual weights.

Keywords
Decision Support Systems, Experience Reuse, Case-Based Reasoning, Quality Improvement

1.INTRODUCTION
Production of cars is a very complex process which involves many process steps. Each step contributes to the variation of the quality of the final product. Therefore, it is essential to have good control over each process as well as the interaction between the ingoing processes. A car body consists of over 350 individual parts which have their own variation, These parts shall be assembled in several steps into the final product – the complete car body. The car body have it's specification to follow, in order to fulfil the demands for mounting of all other equipment in the car. If the car body is out of specification, problems will arise e.g.: bad fitting of interior parts, leakage of sound and water, closing problems with door, hood and other hang on parts. These are just examples of problems which arise due to that the geometry of the car body is out of specifications. The list of problems can be made much longer. Therefore, it is important to understand how each of the ingoing parts and processes affects and interacts with each other. In this study, performed at Volvo Car Corporation, the assembly process of one sub assembly cell (the gore line) for Volvo S80 was analysed. The approach was to investigate a set of selected measurements of the assembled part geometry and compare that to the process adjustments which have been done.

We believe that efficient decision support is helpful in this kind of situation and in this paper we present a method to connect measurements of car body parts to their resulting adjustments done in the production line. Our approach is to investigate a set of selected production measurements and their resulting adjustments to the welding frame. We are also investigating the outcome of the adjustments. The methodology of Case-Based Reasoning (CBR) is applied to enable a connection between measurements, adjustments and their outcome and enable improved performance with increased number of collected cases. This approach enables events of measurements, adjustments and their outcome to be connected and to be saved as cases in a CBR system for future use and re-use as previous similar cases. A case library of such cases is assembled and it will be made readily available to provide real-time decision support in any situation to technicians. Figure 1 depicts a situation of a case solving a problem occurring late in the production line that may result in a defective part if not corrected in time. The case connects measurement features from off-target parts (problems) to action taken previously to adjust production line (solution) to bring production back to target.

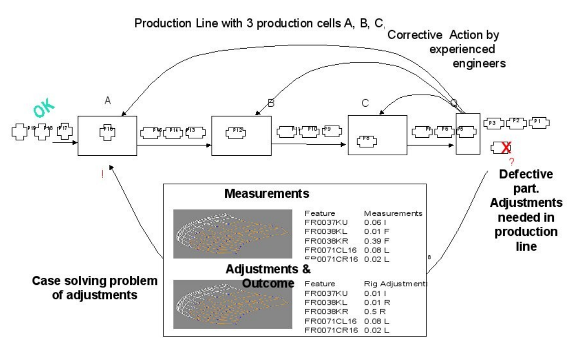

Figure 1. Case solving a problem occurring late in the production line.

In this kind of situation it is vital that the correct cases are retrieved to assure that the correct adjustments are done. We have developed algorithms especially suited for this context to provide efficient case matching, case retrieval and case adaptation to provide technicians with adequate data from previously stored cases of adjustments and their corresponding outcome.

The paper is organized as follows. Section 2 gives a brief introduction to CBR. Section 3 describes our approach of CBR applied to geometric production measurements. Sections 4 describes a prototype system involving a web interface, a server and a database developed for evaluation of our approach in a live production environment and finally section 5 concludes this paper with summary and conclusions.

2.CASE-BASED REASONING

Case Based Reasoning is an Artificial Intelligence method that is inspired by the way humans reuse past experience to solve new problems. It offers an alternative to implement intelligent diagnosis systems for real-world applications [1]. Motivated by the doctrine that similar situations lead to similar outcomes, CBR fits well to classify new measurements or sensor signals based on experiences of past categorizations [2]. The main strength lies in the fact that it enables directly reusing concrete examples in history and consequently eases the knowledge acquisition bottleneck. The CBR methodology is used to solve new problems based on learning from similar cases (i.e. existing experience) stored in a case library that is obtained by storing previous similar situations. It bases its learning from past cases and it has the ability to build up experience, improve its performance and adapt to a changing environment. The CBR cycle is based on four main steps: Retrieve, Reuse, Revise and Retain. The quality of the retrieval process is measured in how well it identifies similar problems that may be reused. Adaptation may also be implemented in the reuse step. Adaptation enables one or more solutions to be adapted to solve a "similar" problem. A proposed solution may be revised to better fit the new problem before it is retained in the case base. A CBR system generally follow this cycle [3] as depicted in figure 2.

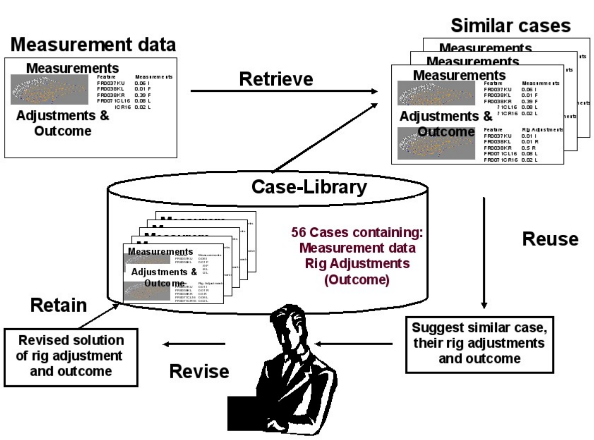

Figure 2. CBR applied to geometric production measurements.

The approach is especially suitable where simulation and modelling is to complex and adjustments cannot be calculated in real time. This is often the case in a real production environment where the relationship between the result and adjustment is so complex that it cannot be predicted, to many factors influence the outcome. Even so skilled technicians learn over time how to adjust in order to get the desired result, experience that may have been acquired trough costly mistakes. CBR enables harvesting this experience and also transferring it between experts and to less experienced experts [4].

3.CBR APPLIED TO GEOMETRIC PRODUCTION MEASUREMENTS

When a novel case is presented to the CBR system a list with similar cases will be presented. This is done using individual weights stored in each of the presented cases. These weights will amplify or attenuate the closeness of the stored case in relation to the novel case. The result will be a list of the nearest neighbouring cases containing candidate solutions according to each set of individual weights stored in each of the cases. Each individual case in this list has a global ranking in the list. The list can be used as decision support for technicians. Cases can easily be browsed using an intuitive web interface and the technician can decide which case or combination of cases to use to guide which adjustments to be done.

In the above manner a possible scenario may contain a number of deviating measurements that may need a combination of stored solutions in order to make a complete adjustment. The technician may use a number of top-ranked cases from the list to perform the necessary adjustments. E.g. case#2 in the list may be similar to deviations in measurement points #1,2,5 presented in the novel case and case#4 in the list may contain solutions to adjustments of deviating measurement point #6 presented in the novel case. The technician can now make a compound adjustment by combining information about adjustment done on case#2 and case#4 and if these adjustments proves to be successful this new compound case may be injected using the web interface into the case base to be used to guide future adjustments.

3.1Case Representation and Case Base

The position of the gore in the car can be seen in figure 3

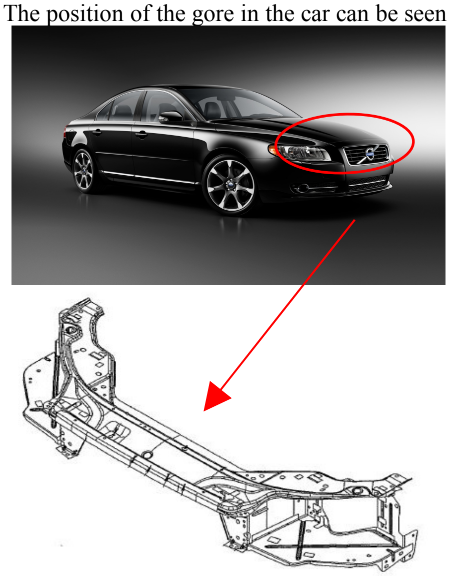

Figure 3. Position of the gore in the car.

The assembly cell can be seen in figure 4.

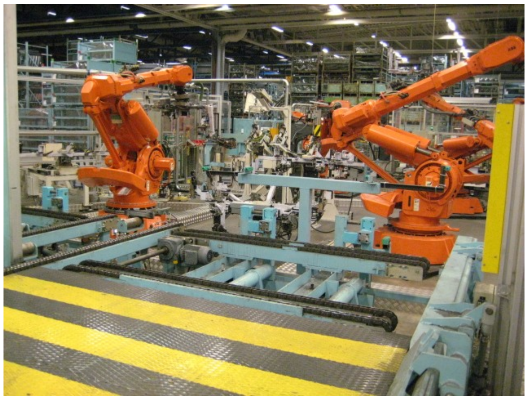

Figure 4. Assembly cell.

The gore consist of nine ingoing parts which each one contributes with it's own variation. The position of the ingoing parts are fixed in an assembly fixture. The internal position of the parts can be adjusted by adding shims at the position of the reference- and support points. Adjustments are used for compensate for the variation of the ingoing parts in order to reach the specification demands on the final sub assembly, the gore. The geometry of the part are controlled by measurement of predefined points , spread over the geometry to reflect the process stability. These points are measured with a Coordinate Measurement Machine (CMM) and indicates if the process are stable or not. If the results indicate that the part is out of specification, problem will arise when mounting the gore into the car and will generate problems such as lamp fixation etc. The parts are continuously measured and stored in a database. Trends can be followed over time since parts are measured during the entire lifetime of the part.

Since the part is very sensitive for variations, many adjustments are required and the experience of the operator, who is responsible, contributes significantly to the quality of the assembled part. A tool for relating how adjustments in the assembly fixture affects the part geometry of the gore would be a valuable tool for the operator in order to take the correct decisions of adjustments of the assembly fixture.

The case base consists of cases containing measurements, adjustments and outcome (results). Each case is represented with a case id. There are 56 cases in total including 290 measurement points, 30 adjustment coordinates and 290 resulting measurement points. Fig 3 depicts the case representation.

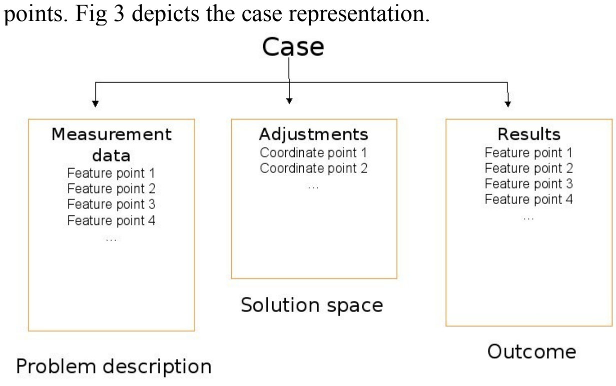

Figure 3. Case representation of geometric production measurements.

3.2 Individual Weighting

To achieve an accurate and realistic matching of cases we intend to find significant measurement points and weight them accordingly. Individual weights are calculated according to relationships between measurements and adjustments using correlation analysis based on the information in the case base. We believe there exist possible relations between one or more measurement points and one or more adjustment points. Also one or more adjustment points can relate to one or more resulting measurement points.

Our main approach is to find all the cases with similar adjustment coordinates and in these cases we investigate whether a relation exists between its measurement points and its resulting measurement points. This is done by calculating the difference between the measurements and the resulting measurement points and then to use correlation analysis to find the relationship between this difference and the adjustments. The resulting candidate measurement points, which may be affected if a certain adjustment coordinate (e.g. coordinate M) alters [5].

When a relationships exist, the affected measurement point can be considered as important as it is shown to have have influence on adjustments. We use this information to calculate weights accordingly. A criterion is set to indicate the strength of a relationship. The criterion has three grades of relationships; strong, medium and non-existent.

3.3 Case-Based Classification using Weighted Measurements

As mentioned before, the features of the problem part of a case consist of sample measurements from a finished body part and the solution part of the case consists of the adjustments done accordingly. Our approach is to match and classify a novel case based on comparing its problem part (ie its sample measurements) with the problem parts of the cases saved in the case base. When matching a novel case all measurements are vital but only cases representing partial (or full) similarities in deviating measurements will be retrieved and these cases will only represent events of successful adjustments with strong correlations between adjustments and measurements as described in the previous section. This is done using individual weights stored in each of the retrieved cases. These weights will amplify or attenuate the similarity of the stored cases in relation to the novel case.

Generally the problem part of the novel case can be described as a feature vector of *n* measurement features and is formulated as (1):

$$FV=\left[m_{1,}m_{2,}\ldots,m_{n}\right] \quad (1)$$

where each *m* a geometric measurement. In comparison, each individually weighted case retrieved from the case base case is formulated as (2):

$$FV=\left[m_1 w_{1,} m_2 w_{2,}\ldots,m_n w_n\right] \quad (2)$$

where each *m* a geometric measurement and w is a weight indicating the strength of the influence *m* as shown to have on resulting adjustments.

We then perform case-based reasoning to achieve a list of the nearest neighbouring cases containing candidate solutions according to each set of individual weights stored in each of the retrieved cases. The retrieval process consists of the following steps: compare the feature vector with the known cases in the library by means of similarity calculation and subsequently select the k nearest cases exhibiting the highest similarity degrees;

Given a feature vector *FV = (m1, m2, ...mn)* its similarity degree with case *C* in the case library is defined as (3):

$$Similarity(FV,C)=\sqrt{\left(\sum_{i=1}^{n} w_i \times (m_i - c_i)^2\right)} \quad (3)$$

where *w1, w2, ..., wn* are attribute weights reflecting different importance of the individual features, c*i* represents the *ith* feature of case *C* and *mi* represents the *ith* feature of feature vector *FV* .

4.4 PROTOTYPE SYSTEM

We have developed a prototype system involving a web interface, a server and a database for classification of geometric production measurements. This has been done in close collaboration with technicians at Volvo.

The system is developed in order to aid technicians to adjust production equipment according to geometric product measurements. The prototype is able to import production data and store in a database accessible from a web interface. The prototype will aid a technician in his daily work in the production line. Also an evaluation of the prototype will be done in order to assess its in-situ functionality at the factory. Figure 4 depicts a screen shot of the prototype system. It displays a nearest neighbour retrieval of stored cases from the case base. The novel case can be seen in the left of the screen, in the middle of the screen is a ranked list of the nearest neighbouring cases and in the right of the screen, further information of a case is displayed when clicking on one of the retrieved cases.

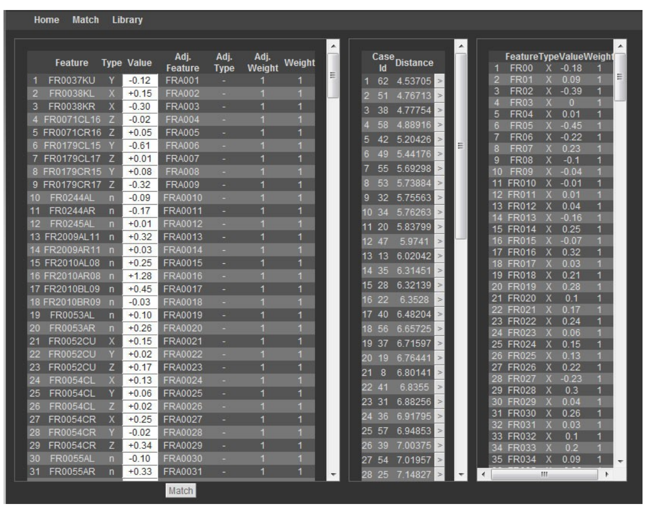

Figure 4. screen shot of the prototype system.

5.CONCLUSIONS

We have shown that Case-based reasoning is a method that can be used to make adjustments to production more efficient by acting as decision support for technicians. The case library stores measurement-adjustment-outcome triplets capturing past experience. These cases can be reused and adapted to the current situation. The system will over time collect considerable experience as the case library grows.

6.ACKNOWLEDGMENTS

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