Design of CF for Automotive Body Parts Based on Artificial Intelligent

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***Abstract*— Checking Fixture (CF) design is an important element in the stamping process of automotive parts and plays an integral role in linking Computer Aided Design (CAD) and Computer Aided Manufacturing (CAM). In order to enhance CF design quality and efficiency, this paper proposes a portable quality-confirmation inspection device for automotive part. The concept of the computer-aided CF design includes a new volume bounding box generation approach for a gantry system framework. Embedded in the system, is a multi objective optimization algorithm which is used for locator layout design and a multi-surface extension and transition method for checking the surface quality. The sensors attached to the system will capture the images of a part and transfer the data into the developed computer system. As an implementation of the CF gantry system, a portable quality-confirmation inspection device for automotive part is developed. Reinforced Front Pillar Panel CF design is taken as a case study to verify it's feasibility and practicability. Based on the initial results, the device is able to give good readings as compared to the manual checking method. Finally, through improvement stages, the system is able to provide an alternative for automotive parts quality confirmation method.**

Keywords*— checking fixture; automotive part; gantry system; computer aided design, optimization algorithm.

I. INTRODUCTION

This template, The checking devices are extensively used in manufacturing industries, especially in the stamping of automotive part. According to An et al. (1999), many CF devices in the marketplace are costly, thus only big company can afford to invest in this fixed device. In this project, in order to design an affordable checking device for all industries including small industries, the effort towards the applicability of this device must be broadened (Kang et al., 2003). Thus, the portable device must be designed in standard sizes that makes it easy to carry from one place to another. This idea is also shared by Krishnakumar and Melkote (2000), who believes that a portable device should be able to carry or move easily, especially due to its lighter and smaller in size than usual checking device.

The general name for checking device is commonly referred as a device for measuring and checking of the linear and angular dimensions of parts and finished products. In addition, Bi et al. (2001) proposed that the measurement device is a technical equipment with standardized parameters or properties that is designed for the experimental determination of the values and physical quantities. When the device is used to determine the dimension, it must comply with all the standard limits and acceptable range, then such equipment is called a checking device. All instruments that can provide dimension and value readings may also be used for checking (Vallapuzha et al., 2011).

CFs for automotive body parts have different types according to measuring planning and parts features. The main types of such CF can be described as follows: measuring fixtures, combined CFs, profile modelling casting CFs, and additional CFs. Selecting an appropriate type of CF for automotive body parts is a first step to design a good CF. In the quality control (QC) process of stamping parts, the selection of which type of CF takes into consideration the features and parameters of the part that need to be measured. Therefore, the characteristics of the stamping part are important to be considered in CF design. Traditionally, selection of a CF type relies heavily on the designer's expertise and experience. Performance evaluation of a CF type is also very difficult due to the highly nonlinear relationship of the design parameters. Consequently, it is not immediately apparent if a CF type is optimal or near optimal for a given part.

Due to the rapid development of the automotive parts, traditional design methods cannot satisfy the demands of these shapes complexities due to the designers' availability. As a result, computer aided fixture design (CAFD) offers an effective solution to overcome these issues. Most current commercialized CF design tools are traditionally geometric-based, in which the experience of designers should be integrated (Wang et al., 2010). Many researchers have introduced knowledge based technologies into this field such as Darvishi and Gill (1990); they illustrated a rule-based method for an optimum solution for a fixture design problem. Then, Hou and Trappey (2001) developed a computer-aided fixture design system based on comprehensive fixture databases and rule-based knowledge. Also, Li et al. (2006) developed an intelligent jig and a fixture design system which applies artificial intelligence (AI) technology. Considering the difficulty in obtaining knowledge, a case-based reasoning (CBR) method is now extensively used in CAFD as mentioned by Liu et al. (2002). They established a case-based agile fixture design system which includes case matching of the fixture planning, conflict arbitration and agile fixture case modification. In case adoption, the most difficult in technique in CBR, there are three methods involved; judging and modifying by users, rule-based variation, and case combination (Chen et al., 2008).

The first method is intuitive and feasible, such as the system of Vukelic et al. (2009), which selects all required fixture elements within particular functional groups by experts. The second one is closely related to the knowledge of fixture design, so a knowledge-based variation mechanism should be created. For example, Chen et al. (2008) proposed a hybrid method which retrieves the similar cases by CBR and adopts them by a rule-based intelligent variation approach. The third one can be interpreted as re-using an element and component levels. Similarly, Wang and Rong (2008) presented a multi-level CBR method for welding fixture design by grading myriads of fixture related resources. However, different from general jigs and other fixtures, CFs are always small-mass manufactured, hence, it is difficult to acquire the knowledge or to re-use past cases. Therefore, the main objective of this research is to develop a methodology to automate the checking fixture design for automotive parts. Four key methods in the implementation are highlighted in this paper. And, a case study is illustrated to show the feasibility and practicability of the system.

II. TYPES AND STRUCTURES OF CF

The CF is designed as a dedicated equipment for a particular automotive part. Normally, CFs for automotive parts are divided into six CF families as shown in Figure 1: light CF, door CF, interior part CF, exterior part CF, glass CF and master model CF. Although the various CFs have different structures, generally, they have similar structures and functions within the same CF family.

Fig. 1. Various types of CFs (Shenmo, 2011)

Practically, there are three important functions of a CF; clamping, checking and locating. CFs are generally composed of four components; locators, clamps or frameworks, checking components or sensors and the workbench or base plate on which other components are placed. Figure 2 shows an RF Fender CF, which belongs to a type of exterior part CF. The position and orientation of the checking part will determine the workbench.

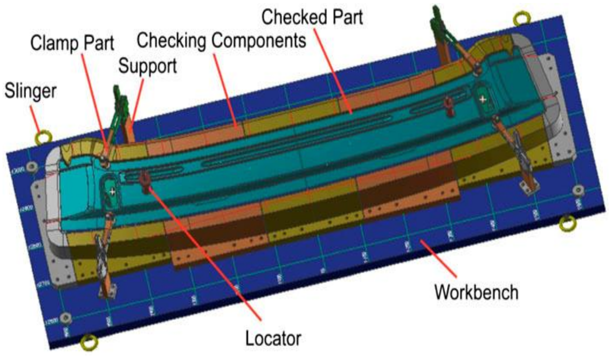

Fig. 2. CF for RF Car Fender part (Jiang et al., 2010)

To position the checking part in static equilibrium, locators are used and thus removing all degrees of freedom. Clamps or frameworks used to support the structure of the device and holding the checking part firmly against the locators. The checking components or sensors are primary in all kinds of the functional components and used to check the part qualitatively or quantitatively and scan the stamping part and transfer the data into the computer system.

III. PORTABLE CF DESIGN

The architecture of the system can be divided into two parts; the main module and the system interfaces. The former supports the CF structure design and the later interacts with the related upstream and down-stream system. The key design process consists of two phases: gantry system design and three functional component design, i.e. locating, clamping and checking. Gantry system is the framework that supports the structure of checking device. The design of gantry system is important because it acts as a workspace for the operation of checking device. In addition, a flexible mounting is developed to re-use and assemble the related standard parts and structures automatically. The system interfaces involve integration with Product Data Management/Enterprise Resource Planning, drawing and Bill Of Material output for manufacturing and quality analysis inspection. Figure 3 shows the flow chart of the design implementation.

A. *Project Initialization*

The first module is to initialize a new project or load an existing one. New project started by specifying the working directory and the measuring unit. After importing the 3D model of the part CAD data and specifying the CF type, the checking fixture design project will be initialized by activating the corresponding design flow.

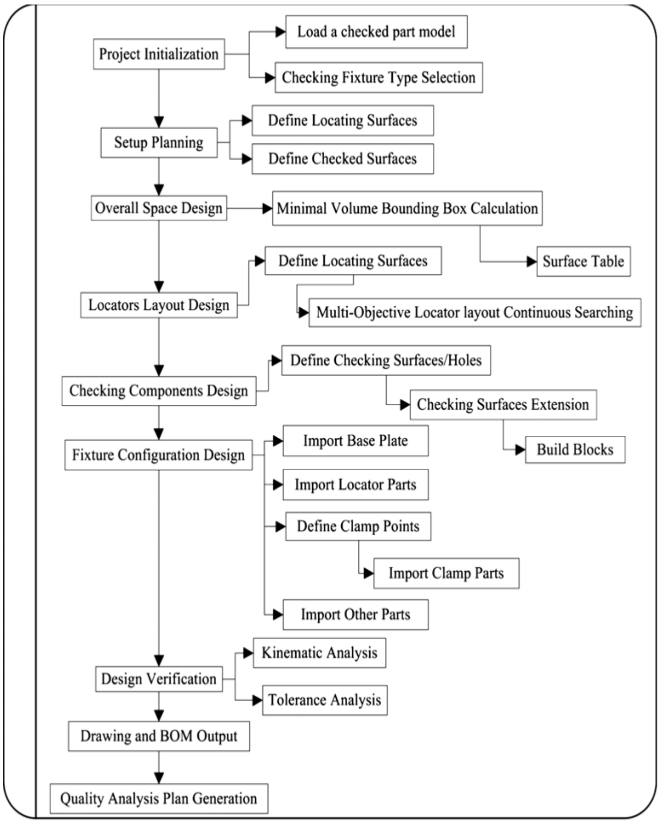

Fig. 3. Flow chart of the system (Jiang et al., 2013)

B. *Setup Planning*

Setup planning involves the identification of setup features, where an individual setup defines the features used in the following phases without altering the position or orientation manually. The key outputs from the setup-planning phase are the identification of each required setup, such as location surfaces and checked surfaces definition as shown in Figure 4.

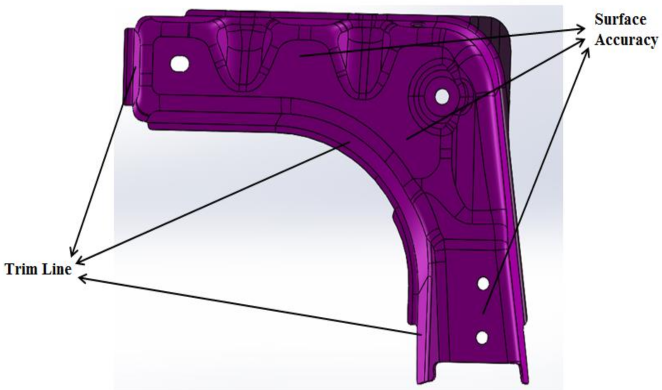

Fig. 4. Locating and checked surfaces

The gantry system idea was illustrated based on a gantry system used in 3D-scanner. In this research, the CF design needs to be portable so that it easy to carry or transfer to various locations. Based on this idea, four CF designs were proposed in order to meet the CF function's criteria. All the four designs were designed using SolidWork2013 software. The drawings were based on part by part assembly process. Some minor adjustments were done in order for the parts to be fitted. Figure 5 shows the design of the gantry system.

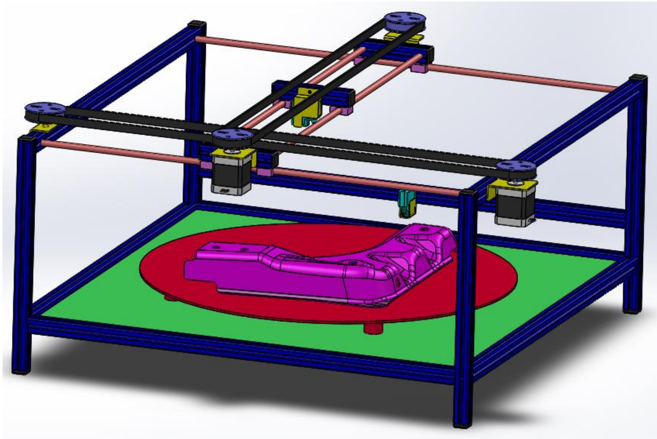

Fig. 5. Gantry system design

C. *Overall Space Design*

In this phase, parts to be checked in the CF will be loaded and assembled as a sub-assembly. Based on the overall dimension of minimal volume of the bounding box of the checking part; a suitable gantry system design will be selected by using minimal volume bounding box generation algorithm for a multi-bodies 3D model. Subsequently, the system draws the scale lines on its top surface for the location and fabrication.

A bounding box is used to establish a suitable overall design space of a CF. There are many bounding box types and algorithms, for instance, oriented bounding box (OBB) (Gottschalk et al. (1996); Eberly (2002)), axis aligned bounding box (AABB) (Mazzetti and Ciminiera (1994); Yamada and Yamaguchi (1996)), minimum-volume bounding box (MVBB) (Gill and Sariel (2001); Chan and Tan (2004)).

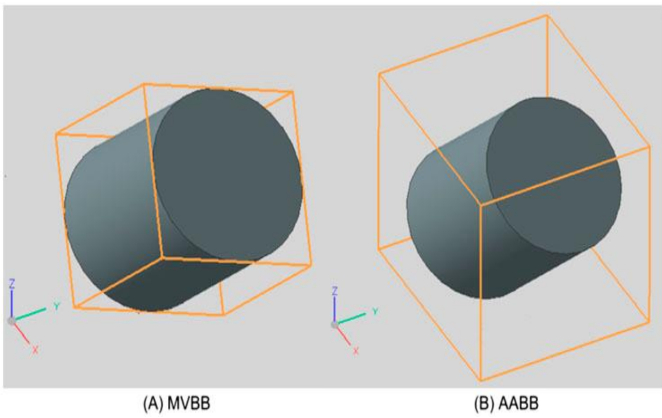

Fig. 6. MVBB and AABB of a cylinder (Jiang et al., 2013)

However, most of algorithms are only applicable to convex hulls (Preparata and Hong, 1977) or facet models (Chan and Tan (2004); Huebner et al., (2008)). Moreover, current commercial CAD software, such as NX, only generates AABB which is generally much larger than MVBB, as shown in Figure 6. Chan and Tan (2001) described a method for determining the minimum oriented bounding box of an arbitrary solid. But this method is only suitable for a single body. Considering a multi-bodies CAD model for checking part models, a minimal volume bounding box (MVBB) generation algorithm is presented in this section.

As shown in Figure 7, V is defined as the volume of the AABB of a given solid and A, B, C are the edge lengths of the bounding box. AB, BC and CD are the rectangle areas of the three mutually perpendicular planes. From the following derivation, we can find that the areas of three mutually perpendicular rectangles of a given box are minimized if and only if the volume of the box is minimized.

$$V = ABC$$
$$V_{min} = (ABC)_{min}$$
$$V^2_{min} = (ABC)^2_{min}$$
$$[(AB)(BC)(CA)]_{min} = (AB)_{min}(BC)_{min}(CA)_{min}$$

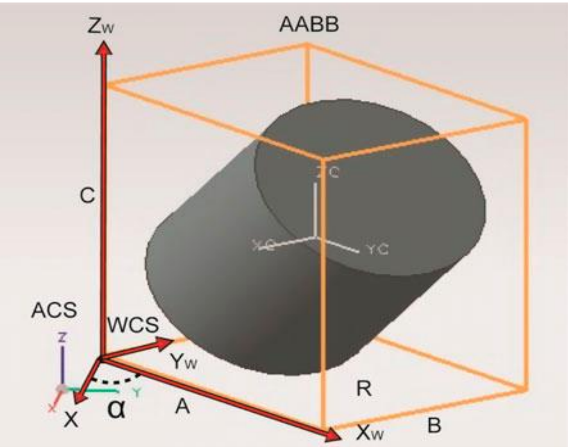

Fig. 7. Schematic of an AABB in WCS (Jiang et al., 2013)

Figure 8 shows the flow chart of the algorithm. Firstly, designer inputs the model of a checked part and set *e* and *d*, which influences the precision and efficiency of the algorithm. V_g is the global minimal volume of AABB of the checking part. Va is the minimal volume when an axis rotation step is finished. For multi-bodies, the whole bounding box volume V can be obtained by six extreme values of corners' coordinate of multi-bodies' AABBs, i.e. $V = (X_{max} - X_{min}) * (Y_{max} - Y_{min}) * (Z_{max} - Z_{min})$. V_r is used to record the temporary minimal volume, and CS_{min} stores the coordinate system where the minimum volume V_r occurs. The algorithm outputs SC_{min}, X_{min}, X_{max}, Y_{min}, Y_{max}, Z_{min}, Z_{max}, which are used to create the MVBB in CAD software.

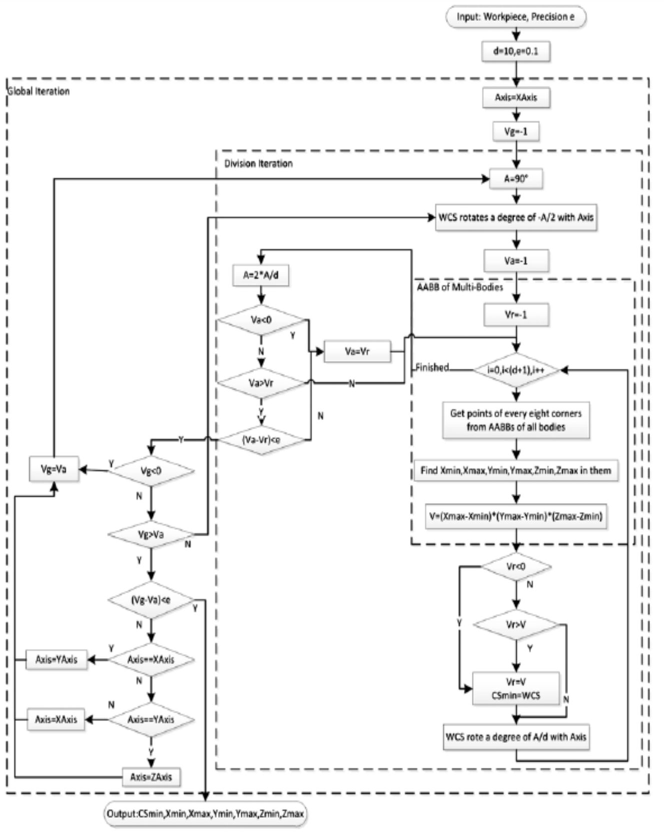

Fig. 8. Flow chart of the terminal volume bounding box generation algorithm (Jiang et al., 2013)

D. Fixture Planning

By using the locator layout multi-objective continuous searching algorithm; an appropriate location and layout can be found to satisfy the requirements of a CF, such as robustness, stability and detachability. After determination of locating surfaces, associated top surfaces and side surfaces should be determined to keep the sub-assembly maintain the stability. On a checking part, the points contacting directly with locators of the fixture are called locating points. The robustness is reflected in the impact on the manufacturing errors of locators. Asada (1985) proposed a geometric perturbation analysis method based on the form closure theory, which used a Jacobean matrix to formulate the relationship between fixture and work piece displacements. Subsequently, Wang and Nagarkar (1999) presented an accuracy optimization against the location errors based on the method. Location stability was defined as the ability to keep contacting with an object without slipping because of unexpected disturbing forces (Nakamura et al., 1989).

Figure 9 shows the proposed multi-objective locator layout continuous searching algorithm, which combines the multi-objective optimization and multiple attribute decision making methods. Firstly, a designer inputs a checking part in CAD software and sets three face sets where locators will be located. The algorithm generates a random individual to initialize the NSGA-II solver. With the established multiple objective problem model in the NSGA-II method generates the feasible solutions space in a multi-objective optimization environment. The Pareto-optimal solutions will be ranked according to the TOPSIS/Entropy method and select the alternatives by using the maximum overall ranking value as the best solution, such as the final locator layout. At last, the positions and directions of locators are shown in the CAD software to guide the designer to import standard locator parts.

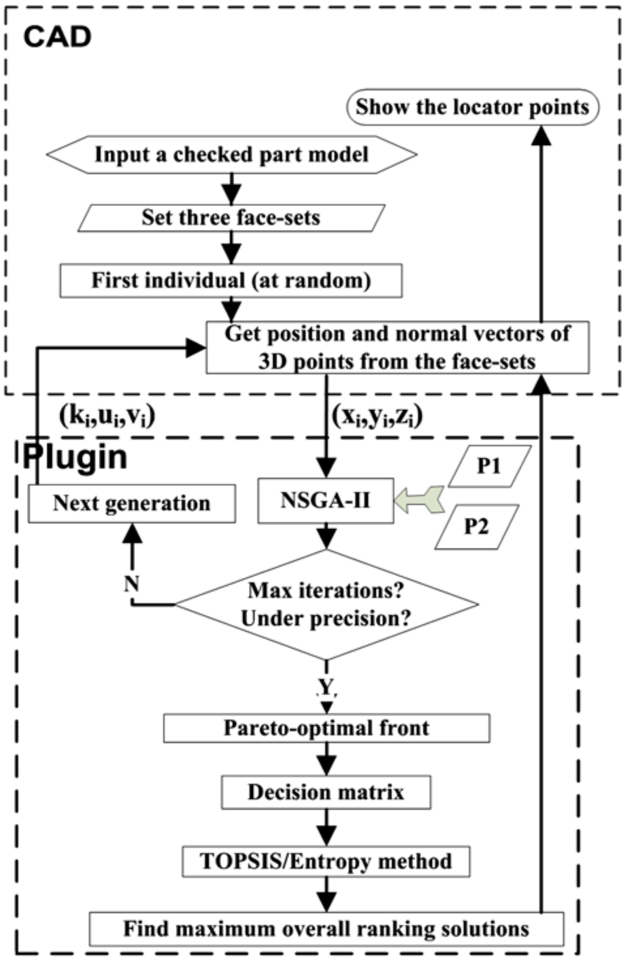

Fig. 9. Flow chart of the locator layout multi-objective continuous searching algorithm (Jiang et al., 2013)

E. Checking Components Design (CFD)

Checking components such as analogue blocks and checking rails are the most complicated parts in CFD for checking whether the shape and precise size of stamping part is under the controlled specification. For instance, an automotive bumper is checked by measuring the gap between its fringes and the top surfaces of the analogue blocks. Checking rails are responsible for checking the Class A surfaces by detecting the slot between the checked surface and the top surfaces of the checking parts.

To match to the surface contour of the checking part usually needs lots of complicated surface extension operations which is one of the most complex tasks in CF design,. Shetty and White (1991) described a method for extending rational B-spline curves and surfaces using knot insertion and the reflection of control points. Furthermore, Pottmann (1995) presented an explicit representation of all rational surfaces with a continuous set of rational offsets. Yu and Lei (1997) introduced an approach to generate extensions of NURBS curves and surfaces satisfying tangent plane and curvature continuities. For a given surface with a piecewise smooth boundary, a new method to extend the surface across its boundary is suggested by Kim et al. (2005). The extended surface is C^2-continuous along the original boundary, and some extra conditions can be imposed on the new boundary.

F. Fixture Configuration System

For this research, the developed CF uses one photoelectric sensor and one distance sensor to shoot and scan the automotive body part which make the checking process become easier and faster. The Arduino Mega 2569 R3 is used as a controller or driver to run the stepper motor and acts as the system memory which enabled the stepper motor moves when input is applied to the system. The data are analyzed using computer software to ensure whether it satisfies the actual CAD data. If the data does not align with the standard result, thus the adjustment of the distance of the sensor must be done until it satisfies the actual CAD data.

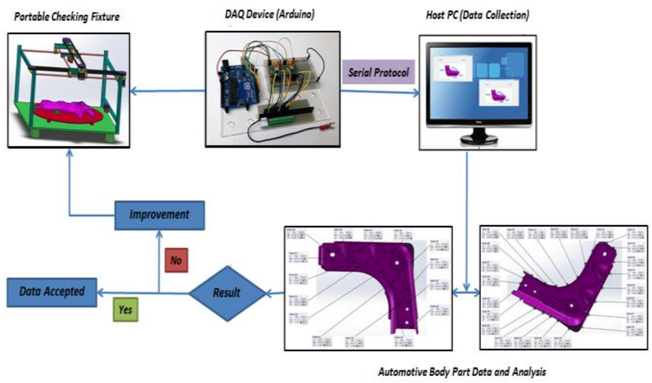

Fig. 10. Portable CF system flow

To ensure this process performs efficiently, all components that we used must be set-up properly such as computer connection with Adruino and Proteus software, power supply of the equipments, and portable CF gantry system is in good condition as shown in Figure 10. In addition, the gantry system must be placed on the levelled ground surface to ensure smooth data transmission to the system.

In part design, designers usually tend to re-use a large number of standard parts and commonly use typical structures which have the same function and similar geometry structure for assemblies, parts and features. The advantages of using this strategy are, firstly, these items is far more cost effective in general. Secondly, re-usable components shorten product design and manufacturing cycles effectively and improve maintenance of the products.

In this section, flexible intelligent part library system (FIPLS) is developed to support checking fixture design more intelligently and efficiently. For the realization of the system flexibility, three methods are proposed. The first method is an extensible part data model to record part information which may vary with parameters and part functions. The second method is the parameter selected dynamical UI for displaying different parameter types. A third method is a four-layer system architecture for adapting to varied Condi- tions and requirements.

G. Design Verification

Verification focuses on ensuring that developed CF designs (in terms of their setup plans, layout plans, and physical units) satisfy the design requirements. The verification will executed according to the following design standards. All the six degrees of freedoms of the checking part should be limited. When the CF components are loaded, there should not be any interference between components and part. The stability of the checking part should maintained, which means no movement is allowed during the checking process. Finally, the parts, CF components should be able to move in and out without difficulty.

H. Drawing and BOM Output

After the completion of CF design, it needs to be reviewed and approved by the chief designer. Subsequently, the designer can deliver engineering drawings/bill of materials (BOM) to downstream production departments. BOM is the term used to describe the raw materials, sub-assemblies, intermediate assemblies, sub-components, components, parts and the quantities necessary to manufacture a part. The quantities of parts to be checked and different kinds of fixture components are listed in the BOM.

I. Quality Analysis Plan Generation

As a high-precision equipment, CF has to be inspected strictly before being delivered to customers. The module helps the designer to generate the quality analysis plan, which guides the operations for inspectors.   Normally two types of data are generated by the CF, trim line and gap analysis. The data is very important for the assembly process with other parts and components. The data will provide the critical areas which are out of tolerances that require improvement to the moulds and dies. The case study based on Reinforced Front Pillar Panel of the checking process is shown in Figure 11. The sample results show that six areas (Points 21, 22, 24, 29, 30, 31 and 34) need to be improved. The remaining areas are in good condition and no further action is required in theses areas.

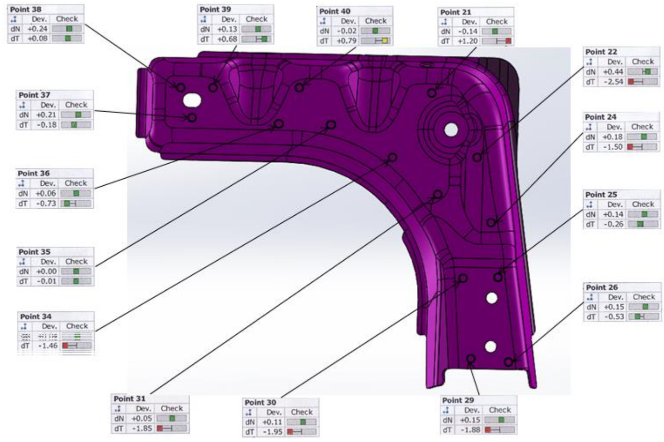

Fig. 11. Results of the automotive body part checking

IV. CONCLUSION

This paper intended to introduce a development concept of a portable quality-confirmation inspection device for automotive body parts. In inventing a good portable CF device, the characteristics of the portable CF device and the design of a gantry system need to be considered. The design of a gantry system is important because it acts as a workspace for the operation of CF device and as the framework that support the structure of CF device. To achieve an efficient method, the integration of all the four steps of CF design, (setup planning, fixture planning, unit design, and verification), needs to be considered. Beside that, there is also a need to control the techniques for the verification and optimization of CF performance so that reliable data is captured during the process.

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