Non-reproducible alignment and fitting algorithm effects on Laser Radar measurement

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***Abstract*—Ever-increasing introduction of new production technologies has significantly reduced manufacturing cycle time in recent years, especially joining technologies. For many industries, Zero Defect Manufacturing (ZDM) is considered as a key strategy to improve Right -First -Time (RFT) capability with a minimum waste of resources. There is a growing desire to move from off-line sample measurement to in-line data collection, which will only be possible with fast, accurate measurement technologies. Although metrology cycle times have improved with in-line measurement systems, their accuracy is not sufficient to meet the tight tolerance demands of typical high value manufacturing applications. A major obstacle to the uptake of new, non-contact measurement technologies is the difficultly in evaluating system capability in terms of repeatability, accuracy and calibration to recognized standards. This study considers these characteristics for a Laser Radar (LR) measurement system applied to an automotive door measurement task. To evaluate these factors, the authors consider: (1) the effect of tooling ball (TB) position and movement on part alignment and measurement feature results and (2) the feature-fitting algorithms applied to different sizes and orientations of hole. The results show that the statically-mounted LR is good at developing a repeatable coordinate system for the workpiece. Offsetting an individual TB had a statistically significantly effect on the repeatability of the measurement results. A number of feature-fitting algorithms were studied, with no algorithm providing a definitively superior result. Two data capture algorithm were considered; hatched and petal algorithm. The petal pattern algorithm is much faster, and was found to provide comparably repeatable results as the hatched pattern algorithm. These results give confidence that the LR system demonstrates good repeatability.**

I. Introduction

In recent years, manufacturing companies have adopted a Zero Defect Manufacturing (ZDM) approach to reduce product defects and to improve Right-First-Time (RFT) capability with minimum waste of resources [1]–[3]. In order to achieve ZDM, data collection alone is not sufficient; data mining methods are critical to evaluate the inherent variation of manufacturing processes. During New Product Introduction (NPI), Statistical Process Control (SPC) and similar tools are used to identify and eliminate defects from occurring/reoccurring. In the automotive industry inspection is typically performed using Coordinate Measuring Machines (CMMs) [4], [5] that provide high accuracy and repeatability, but are housed in dedicated off-line facilities that require a controlled environment [6], [8]. This off-line process is time consuming and only a limited number of samples can be measured. There is a rising trend to move away from off-line sample measurement to in-line data collection in order to predict defects before they happen or identify trends in the production process [9], [10].

Over the last decade, in-line metrology solutions have become increasingly advanced and automated and more prevalent in manufacturing systems [11]. Although the potential opportunities of in-line measurement systems are clear, there are a number of challenges to be addressed if their benefits are to be realised across a range of production applications. Components with high manufacturer tolerances present a big challenge in terms of accuracy and repeatability. Determining measurement uncertainty for a specific measurement task through use of CMMs is well defined for running comparisons with non-contact measurement systems [12], which are a sensitive to typically material conditions such as surface reflectivity and colour [13], [14]. It is important to control environmental factors such as temperature, vibration and lighting so the impact on measurement is minimised. In automotive industry, the measurement time of a workpiece has become dramatically greater than before because of the increasing complexity of manufactured parts. This makes it more difficult to use non-contact technologies as an in-line measurement system in order to perform measurement within process cycle time, which are generally around 70 seconds or less.

There are two main difficulties when measuring dimensional and geometrical variations in order to capture the important geometric relationships in a workpiece/sub-assembly, which are alignment and fitting algorithm. It is critical for the operator to understand these specifications and to capture them appropriately using the measurement machine and its software when inspecting workpieces. First, the measurement of datums is an important phase in accurately, determining position conformance [6]. Both the measurement and the measurement part are not perfect in real part measurement. Second, the variation in measurement results is a consequence of different (and incomplete) workpiece information being provided to the fitting algorithm because of the finite number of measured points. There will always be a difference between the manufactured geometry and the substitute geometry when

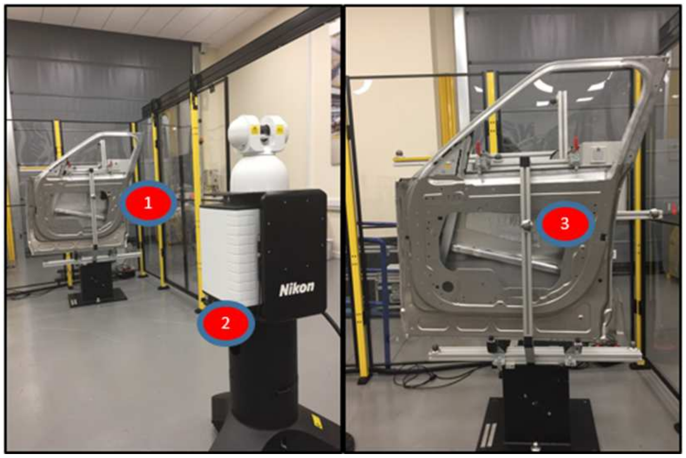

Fig. 1: Experiment Set-up (Labels: 1.Workpiece, 2.LR, 3 TBs)

the workpiece is closely sampled. Both are sources of measurement uncertainty because of sampling strategy; hence, the effect of the sampling must be accounted for when determining the combined standard uncertainty of a measurement system [6], [15].

In a previous study, the authors demonstrated LR as an in-line metrology system in the context of Body-In-White inspection process [16]. The objective of this paper is to evaluate the impact of non-reproducible alignment and fitting algorithm selection on measurement results. The automotive artefact selected for this study was an aluminium automotive door assembly (Jaguar Land Rover Limited, UK) on fixture as seen Fig.1.

II. Materials and Methods

MV330 Laser Radar (Nikon Metrology, UK) was used in this measurement study. It has two rotary axes, azimuth and elevation, controlled by separate encoder feedback and a unique range measurement achieved by comparing two wave forms of an infrared (IR) laser beam with a frequency modulated chip. The LR mixes the IR energy reflected off the workpiece with an internal IR signal to measure the maximum return energy. Laser interferometry was used to calibrate the range based on ASME B89.4.19 [17]. The resolution of Azimuth and Elevation are 0.018mm and 0.039arcs-sec respectively, with an expanded uncertainty (k=2) of 6.8μm/m. Polyworks 2016 IR4 software (InnovMetric Software Inc., QC, Canada) was used for the LR measurement programme. For the fitting algorithm, two different algorithms were used; which are Petal Pattern and Surface Scan. Petal Pattern algorithm was used as developed by Nikon Metrology. A number of scan lines are taken across the hole with filters applied to remove points that are on hole chamfers and at the bottom of holes. Five scans were used for fitting circles in this study. Surface scan, developed by Polyworks does a box scan around the circle to create a point cloud in order to extract the measured circle from the data and nominal values. When extracting measurement features from a point cloud, three methods can be used to specify how the feature should be fit. In this study, the Min method was selected so the feature is fit such that no points are enclosed by primitive. There are three parameters identified to fit the circle; point spacing, line spacing, and scanning zone. In this study, these are 0.1mm, 1mm, 5mm clearance to the hole respectively.

A. *Experimental set-up*

The automotive artefact was located on the fixture for the duration of the study in a temperature control environment at $22°C \pm 1°C$. The LR required two levels of alignment. To define the alignment of the workpiece four holes were measured and aligned using the centre points alignment method to transfer the coordinate frame of the LR into the local part coordinate frame of the workpiece (car-line alignment). The six TBs (Grade 25, spherically 0.6μm and $\pm$ 2.54μm diameter tolerance) positions were then determined relative to the local coordinate system and set as secondary reference points. It can rescan these TBs as targets in order to update the LR position. In summary, the LR could locked back into the same alignment using just the TBs. Then, these six TBs were measured to update the datum for each run.

B. *Reproducibility*

For the reproducibility test seven features were measured: one hole, two slots, two surface points, and one matte TB were measured based on each new alignment. There are two parts for reproducibility experiment, First, six matte TBs were used for alignment for the first thirty measurements. In the following measurements, each TB position was altered by putting a metal shim (thickness of 0.004inch = 101.6μm) between one TB and the holder. The same alignment procedure was carried out and the six features were measured. This was repeated for each of the six TBs used for alignment. Finally, matte TBs were replaced with shiny ones for the last thirty measurements. The second part of the experiment is to understand effect of number of TBs used on alignment on measurement result, the number of TBs were not included each time to the alignment procedure.

C. *Fitting Algorithms*

For the fitting algorithm experiment, seven holes ranging from 5.2mm to 60mm were measured using four different methods using two different algorithms. These are the petal pattern method (algorithm developed by Nikon), the minimum method with surface scan parallel to the longest side of the feature (long-side pattern), the minimum method with surface scan parallel to short side of the feature (short-side pattern), the minimum method with hatch pattern (combining of the longest and the shortest line scan). The last three method used the same minimum-fitting algorithm developed by Polyworks. The parameters used for surface scan were point spacing and line spacing, which were 0.1mm and 1mm respectively. For the petal pattern method, five scan passes used. To compare the mean position and the standard deviation were calculated from 240 sets of measurement for the reproducibility experiment

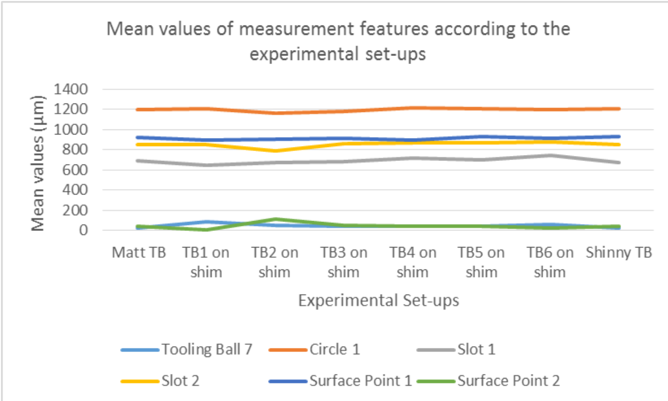

Fig. 2: Mean values of measurement features according to the experimental set-ups

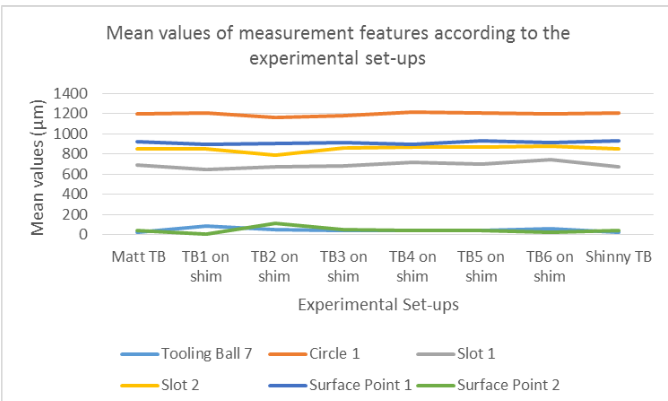

Fig. 3: Standard deviations of measurement features according to the experimental set-ups

and 30 sets for fitting algorithm experiment. To evaluate the overall measurement performance different set-ups, paired T-Test and ANOVA for mean difference and correlation analysis for the measurement results were performed. All calculations were performed in Minitab 17 Statistical Software (Minitab, State College, PA: Minitab, Inc.)

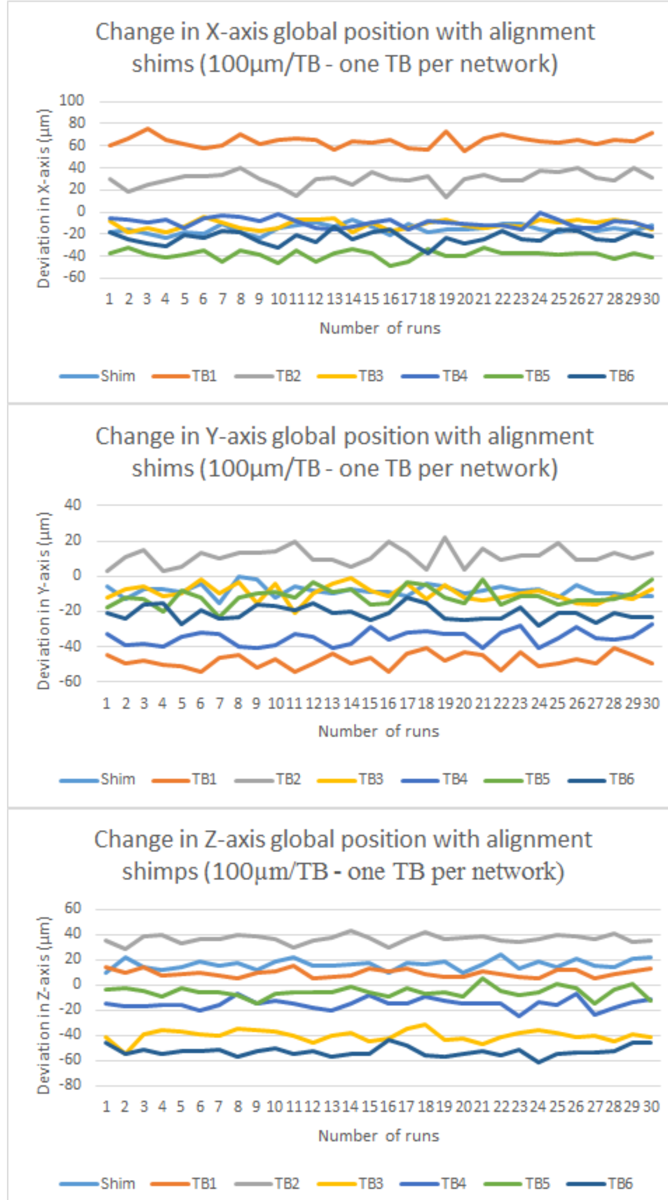

Fig. 4: Change in co-ordinate axis one TB per network

III. Results

The reproducibility experiment showed no significant statistical difference (both p-values is bigger than 0.05) between using matt and shiny TBs for alignment to the workpiece. Similarly, altered tooling ball position each time with a metal shim (101.6μmm) had no considerable impact on means of measurement features and standard deviation as seen Fig.2 and Fig.3. This is important to manufacturers if anything happens in the measurement set-up, especially large-volume manufacturing; updating the LR position by rescanning TBs is sufficient to maintain the measurement accuracy without the need for recalibration. For example, physical knocking of a TB and replacement could happen in any production environment. However, changing each TB showed a method change and shift in results; hence, this change is small and the range up to 75μm in any direction, as shown in Fig.4.

For the fitting algorithm experiment, there is no correlation between hole size and any of the four fitting patterns. The average standard deviation of each pattern is around 0.02 for each circle; hence, their repeatability is good. Fig.5 shows the number of points in the scan that were being used within extraction. Considering that the petal pattern collected just 350 points for each circle which is several orders of magnitude less than the typical hatched pattern, this is an impressive result. For example, the number of points were used the smallest hole (5.2mm) and the largest hole (60mm) was 1600 and 14665 respectively. These results also reflects an increasing time required to measure a hole significantly. Given that this

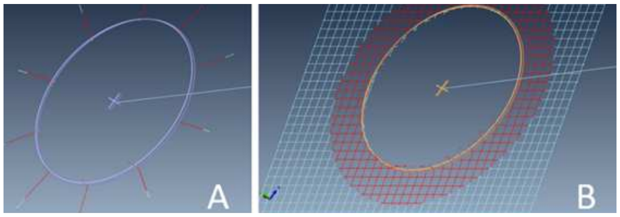

Fig. 5: The number of points in the scan that were being used within the extraction by Petal (A) and Hatch algorithm (B)

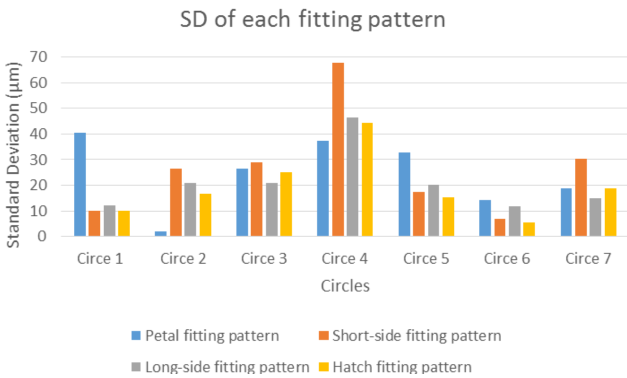

Fig. 6: Circles deviation compared to reference hatch fitting pattern

is 25μm in absolute value, this could be sufficient for a number of applications where there are high cycle times.

To measure a hole with petal pattern algorithm took 3s for the 5.2mm diameter of the hole (the smallest hole in the experiment), 5s for the 60mm diameter of the hole (the largest hole in the experiment). The time measuring with hatch pattern comparing with the petal pattern algorithm took three times more for the smallest hole (10s), eleven times more for the 20.11mm diameter of the hole (53s), and 44 times more for the largest hole (215s). The repeatability of the circle measurements was also considered for each pattern as seen in Fig.6. Here it is seen that the standard deviation of 30 measurements were similar across all patterns. The gain in time advantages and similar repeatability makes the petal algorithm an attractive prospect.

The hatch fitting pattern is currently preferred method in LR. The measurements of seven circles were compared via the hatching fitting against long-side, short-side and petal-pattern fitting as shown in Fig.7. Here it is observed that the long and short-side patterns differed by up to 8%. With the exception of circle 1, the petal pattern had a maximal deviation of 11%. However, the time to measure a hole with hatch pattern is twice as long as either long side or short-side pattern because hatch pattern combines long and short-side pattern as seen Figure 8. Apart from Circle 1, petal-pattern algorithm did not deviate more than 11%; thus is quite good result if compared with the number of points collected and little time for performing measurement.

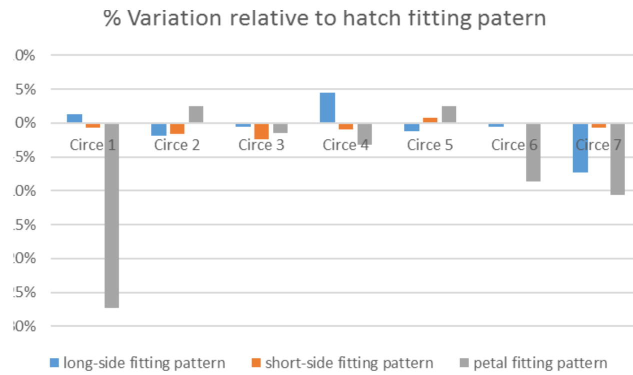

Fig. 7: Comparison of standard deviations for fitting patterns

IV. Conclusion

The alignment procedure could determine the coordinate system locations relative to the workpiece. Any variability in the coordinate system will contribute the uncertainty of other measurements on the workpiece. Based on study results, the LR is good at developing repeatable coordinate system for the part. It was found that offsetting the TB didnt significantly impact the measurement result but there was a shift in co-ordinate axes up to 100m. Petal pattern is considered an alternative due to time saving. Clearly, it is repeatable and the variance potential is up to 11% the featured measured. Where the cycle time of hatch is too long, means that petal might be viable depends on feature tolerances. Future work needs to be done to use a calibrated artefact and to scan different kind of features, such as round slots, with manufactured by different manufacturing technologies, such as machining, punching. This will help to identify which algorithm is more accurate.

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