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# Compensation of Installation Errors in a Laser Vision System and Dimensional Inspection of Automobile Chassis

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Laser vision inspection systems are becoming popular for automated inspection of manufactured components. The performance of such systems can be enhanced by improving accuracy of the hardware and robustness of the software used in the system. This paper presents a new approach for enhancing the capability of a laser vision system by applying hardware compensation and using efficient analysis software. A 3D geometrical model is developed to study and compensate for possible distortions in installation of gantry robot on which the vision system is mounted. Appropriate compensation is applied to the inspection data obtained from the laser vision system based on the parameters in 3D model. The present laser vision system is used for dimensional inspection of car chassis sub frame and lower arm assembly module. An algorithm based on simplex search techniques is used for analyzing the compensated inspection data. The details of 3D model, parameters used for compensation and the measurement data obtained from the system are presented in this paper. The details of search algorithm used for analyzing the measurement data and the results obtained are also presented in the paper. It is observed from the results that, by applying compensation and using appropriate algorithms for analyzing, the error in evaluation of the inspection data can be significantly minimized, thus reducing the risk of rejecting good parts.

**Key Words :** Laser Vision System, Error Compensation, Dimensional Inspection, Simplex Search

## 1. Introduction

The performance of an automobile can be guaranteed only if its main components and assemblies are dimensionally accurate. Hence dimensional measurement and evaluation play a significant role in the automotive industry to ensure the quality of an automobile. These components have to be inspected using compatible inspection machines and procedures to verify them during the manufacturing process itself. Various non-contact methods such as stereo vision and specular reflection (Kosmopoulos et al., 2001), photogrammetry (Beyer, 1995) etc. were used for inspection of automobile parts. Significant progress in this area started with utilization of laser-based machine vision technology which provides high speed measurement (Park et al., 2003), about 20, 000 points/sec along with non-contact and on-line inspection capabilities (Prieto et al., 2002). Thus a large number of measurements can be performed quickly and simultaneously without physically making contact with the automobile body. Due to these capabilities laser measurement systems can be placed "in process" to measure 100% of production (Gilbert, 2002 ; Yoon et al., 2005). Camera and laser based range and position sensors (laser triangulation sensors) are now widely used in 3 dimensional measuring systems

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to meet the demands of good flexibility and high speed (Malamas et al., 2003). The common arrangement for verifying the dimensional accuracy of automobile components is by using laser sensors mounted on industrial robot (Brunk, 1982; Park, 1992; Shen, 1999).

It is common practice to use calibration for enhancing the performance of the machine tools, CMM and robots using calibration method. Calibration is very effective in correcting both static and dynamic errors such as structural errors, installation errors, thermal errors, errors due to wear and tear etc. They are easy to implement and also cost effective. Harris and Spence presented an error compensation method for CMM positioning errors (Harris et al., 2004). Meng et al proposed a direct error compensation method using software and hard ware compensation for a six degree freedom parallel mechanism CMM (Meng et al., 2002). It is very difficult to construct perfect machines despite the perfect design, due to introduction of various errors during installation and operation. It is much easier to measure the amount of inaccuracies and compensate them (Ramesh et al., 2000). Lenz and Tsai developed a geometric calibration method for Cartesian robot, with eye-on-hand configuration, to enhance the accuracy of overall system (Lenz et al., 1989).

A common need in machine vision is to compute the 3-D rigid body transformations that align two sets of points for which correspondence (Lee et al., 2004). The relationship between two reference coordinates is represented as multiplying of coordinate transformations matrices. For the best fitting between coordinates, there is the least squares method based on Singular Value Decomposition and Lagrange multiplier, which is used for mapping inspection and design data (Lee et al., 2004). The data obtained from these inspection systems have to be interpreted using robust programs to analyze the acquired data and make appropriate decisions. Many software tools such as neural networks, fuzzy logic, genetic algorithms etc. are used for interpreting the data obtained from inspection systems (Li et al., 2004). The simplex search method is used in many engineering applications to obtain local and global minima (Luersen et al., 2004).

In the present work, a 3D model of the laser vision system, used for inspecting sub frame and lower arm assembly of an automobile chassis module, is developed. Using this model, appropriate compensation is given to compensate installation errors in the system. The data obtained from the inspection system after applying appropriate compensation is analyzed using an algorithm based on simplex search technique. The results of inspection and evaluation of dimensional errors in an automobile front chassis module are presented in this paper. The results of dimensional error evaluation after applying the 3D compensation proposed in the present work are compared with those obtained without compensation.

## 2. Description of Laser Vision System

The present system consists of gantry robot equipped with laser vision system mounted on its movable arm. The overall system with gantry robot and laser vision system mounted on it is shown in Fig. 1. Chassis module dimensions depend on car model and are normally within the range 1.5 to 2.0 m, so laser sensor should travel about that distance. Hence, the present laser triangulation sensor system is mounted on a gantry robot. This robot has parallel synchronized horizontal axes X1 and X2, perpendicular horizontal

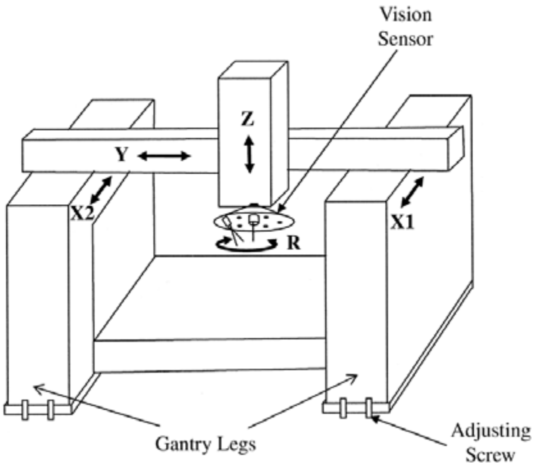

**Fig. 1** Laser vision system

axis Y, vertical axis Z and rotational axis R. The distance between horizontal axes X1 and X2 according to the gantry specification is 2190 mm.

By using this system the coordinates of any point in space in the range of laser can be determined. This system also incorporates a Charge Coupled Device (CCD) camera and LED light sources. The LEDs are provided for illuminating the target and to enhance the edge detection capability of the system without being affected by ambient lighting. The CCD camera captures the image. Laser Sensor arrangement is shown in Fig. 2.

The laser triangulation system consists of a laser diode, a receiver lens, a scanning mirror and an image detector. Often the last two are combined within commercial compact CCD camera. The laser beam is directed perpendicular to the object's surface and image detector and lens are inclined at some angle as shown in Fig. 3. The laser diode projects a beam that is directed on the target and an image of the target with the laser beam will be captured by CCD camera. Relating the pixels of the image captured by CCD camera with the corresponding 3D points of the part being measured, the coordinates of the required point can be measured.

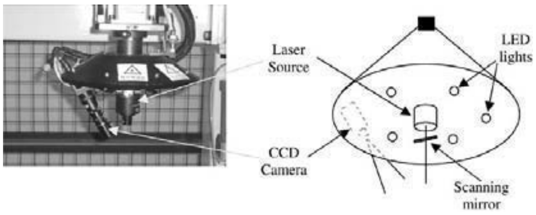

**Fig. 2** Laser sensor arrangement

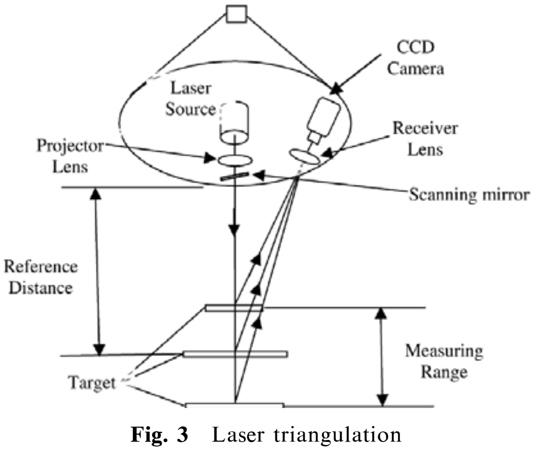

**Fig. 3** Laser triangulation

## 3. Chassis Module and Measurement Method

One of the car's critical assemblies, whose dimensional distortions can cause poor performance of an automobile, is chassis module sub frame assembly. The front chassis module with sub frame and lower arm assembly is shown in Fig. 4. There are six main points on this module i.e. four flanges ($P_1$ to $P_4$) on the sub frame and two flanges on the lower arm ($P_5$ and $P_6$). The position of points $P_5$ and $P_6$ on the lower arm are more crucial as the strut will be mounted on it through king pin and ball joint. The four flanges ($P_1$ to $P_4$) are fixed. On the other hand, the points $P_5$ and $P_6$ where the king pin and ball joint will be mounted, can rotate about a center tracing an arc which is a part of a circle. In order to determine the position of the points $P_5$ and $P_6$ as specified in the design, the lower arm is rotated to different positions and the arc traced by these points is obtained. In the present system, the measurements are taken at three positions such as $P_{m51}$, $P_{m52}$, $P_{m53}$ and $P_{m61}$, $P_{m62}$, $P_{m63}$ for left and right lower arm respectively. A SCARA (Selective Compliance Articulated Robot Arm) Robot is used for moving the lower arm to different positions. A circle is fit using these three points

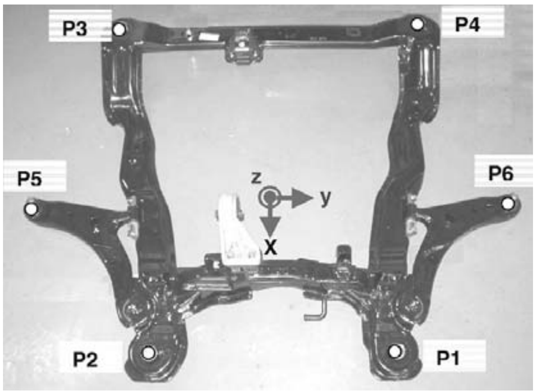

**Fig. 4** Automobile front chassis module

**Table 1** Design specifications of automobile front chassis module

| Point No. | | x (mm) | y (mm) | z (mm) |
|---|---|---|---|---|
| Points on sub frame | $P_{d1}$ | 438.00 | 318.00 | −3.00 |
| | $P_{d2}$ | 438.00 | −318.00 | −3.00 |
| | $P_{d3}$ | −622.00 | −494.00 | 93.00 |
| | $P_{d4}$ | −622.00 | 494.00 | 93.00 |
| Points on lower arm | $P_{d5}$ | −15.30 | −723.90 | −78.20 |
| | $P_{d6}$ | −15.30 | 723.90 | −78.20 |

and the position of the point is obtained on this circle when the Z-coordinate is −78.2, as specified in the design (refer Table 1). In the present paper the design points on the chassis module are represented with suffix *d* and measurement points with suffix *m* for convenience.

## 4. Gantry Model and Calibration

The 3D model of the vision system is shown in Fig. 5. The gantry axis X1 is taken as the reference and it is along the X axis of reference coordinate system. L1, L2, L3 and L4 are on the base on which the columns of the gantry robot are mounted.

In ideal case, the origin of axis X2 should lie on the perpendicular to the axis X1 and at distance $l_0$ from it. But in practice, it is impossible to install the gantry columns precisely. Due to errors in gantry's installation the origin of X2 axis is shifted from its ideal position by vector $\vec{h}=\{h_X, h_Y, h_Z\}$. Axis X2 is tilted in 3D by angles $\theta_X, \theta_Y$ and $\theta_Z$ relatively to axes X, Y and Z. These angles are linked by the following equation for direction cosines:

$$\cos\theta_Z=\sqrt{1-\cos^2\theta_X-\cos^2\theta_Y} \tag{1}$$

The angle $\theta_X$ is nearly equal to 0° with its cosine value close to 1, the angles $\theta_Y$ and $\theta_Z$ values are about 90° and their cosines are small. The distance from axis X2 origin to the point P2 is X2′. The origin of Y axis is shifted from imaginary crossing point with X1 ball screw axis by the value $S_Y$.

The actual distance between points P1 and P2 can be found as follows

$$l=\sqrt{(h_X+X2'\cos\theta_X-X1')^2+(l_0+h_Y+X2'\cos\theta_Y)^2+(h_Z+X2'\cos\theta_Z)^2} \tag{2}$$

Then the coordinates of any point P measured by the system can be derived as follows:

$$x=\frac{(h_X+X2'\cos\theta_X)\,Y'+X1'(l-Y)}{l} \tag{3}$$

$$y=\frac{(l_0+h_Y+X2'\cos\theta_Y)\,Y'}{l} \tag{4}$$

$$z=\frac{(h_Z+X2'\cos\theta_Z)\,Y'}{l} \tag{5}$$

Also axis Z is tilted and makes angles $\psi_X$, $\psi_Y$ and $\psi_Z$ relatively to reference axes X, Y and Z and their cosines are linked as

$$\cos\psi_Z=\sqrt{1-\cos^2\psi_X-\cos^2\psi_X} \tag{6}$$

Axis Z origin is shifted by $S_Z$ along the Z axis, so actual $z$ coordinate can be found as

$$z=\frac{(h_Z+X2'\cos\theta_Z)}{l}-S_Z \tag{7}$$

The parameters of the model which are required to determine coordinates of the point inspected by the system are as follows:

$h_X$ - origin shift of axis X2 in X direction
$h_Y$ - origin shift of axis X2 in Y direction
$h_Z$ - origin shift of axis X2 in Z direction
$\theta_X$ - inclination of axis X2 with reference to X
$\theta_Y$ - inclination of axis X2 with reference to Y

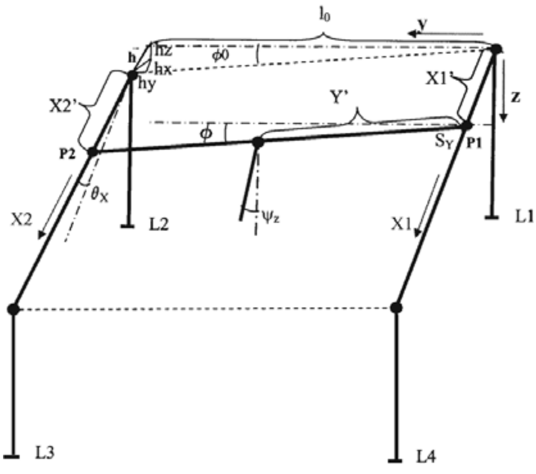

**Fig. 5** 3D gantry model

**Table 2** Measurement data obtained for the Golden sample from a CMM and Laser Vision system (After transformation)

| Point No. | CMM (mm) | | | Laser Vision system (mm) | | |
|---|---|---|---|---|---|---|
| | x | y | z | x | y | z |
| $P_{g1}$ | 437.997 | 318.004 | −3.000 | 437.887 | 317.805 | −3.057 |
| $P_{g2}$ | 437.997 | −318.004 | −3.000 | 438.261 | −318.378 | −2.866 |
| $P_{g3}$ | −622.034 | −494.176 | 93.045 | −621.401 | −493.053 | 92.844 |
| $P_{g4}$ | −621.957 | 493.924 | 92.857 | −621.747 | 493.627 | 93.079 |
| $P_{g5}$ | −15.473 | −724.450 | −77.921 | −14.244 | −723.681 | −78.200 |
| $P_{g6}$ | −15.697 | 724.450 | −78.086 | −15.480 | 723.859 | −78.200 |

$\psi_X$ - inclination of axis Z with reference to X
$\psi_Y$ - inclination of axis Z with reference to Y
$K_{X1}$ - ball screw pitch error coefficient of axis X1
$K_{X2}$ - ball screw pitch error coefficient of axis X2
$K_Y$ - ball screw pitch error coefficient of axis Y
$K_Z$ - ball screw pitch error coefficient of axis Z

In order to obtain the required parameters of the 3D model, a precisely manufactured chassis module called as "golden sample", is prepared. This sample is manufactured in such a way as to have close to zero dimensional errors. The golden sample is measured using both a CMM and the present laser vision system. The relation between the values of CMM data and the data obtained from present system are used to determine the values of different parameters required in the 3D model of the system. The measurement data for golden sample obtained using CMM and present laser vision system is shown in Table 2. The golden sample data represented with suffix $d$. In the present work, a Monte-Carlo simulation is carried out to obtain the optimal values of the required parameters. After obtaining the values of required parameters, the actual x, y and z coordinates of the point P are determined using Equations 3, 4 and 7 respectively.

## 5. Analysis of Measurement Data

After obtaining the measurement data for required points from the laser vision system the actual coordinates of the inspection points are determined by applying the compensation for installation errors by using equations 3, 4 and 7 mentioned in the earlier section. This data is referred as compensated measurement data. This data has to be analyzed to determine dimensional errors and verify the conformity of the parts to the design specifications. In the present system, the compensated data is analyzed using simplex search techniques to determine measurement coordinate system and dimensional errors in an automobile front chassis module.

### 5.1 Establishing measurement coordinate system using simplex search technique

The geometric figure formed by a set of n+1 point in an n dimensional space is called simplex. The simplex in two dimensions is a triangle and in three dimensions it is a tetrahedron and so on. The basic idea in the simplex method is to compare the values of the objective function at the n+1 vertices of a general simplex and move the simplex gradually toward the optimum point during the iterative process.

The following equation can be used to generate the vertices of a regular simplex of size a in the n-dimensional space.

$$X_i = X_0 + p u_i + \sum_{j=1, j\neq i}^{n} q \mathbf{u}_j \quad i = 1, 2, 3, \cdots, n \tag{8}$$

where

$$\begin{aligned} p &= a/n\sqrt{2}\left(\sqrt{n+1} + n - 1\right) \\ \text{and } q &= a/n\sqrt{2}\left(\sqrt{n+1} - 1\right) \end{aligned} \tag{9}$$

$X_0$ is the initial base point and $u_j$ is the unit vector along the $j^{th}$ coordinate axis (Prieto et al., 2002). The simplex search uses the concepts of reflection, expansion and contraction to arrive at the minimum solution.

The design specifications of the sub frame and front lower arm are shown in Table 1. Points $P_{m1}$ to $P_{m4}$ on the sub frame are considered for determining the measurement system. For instance the x coordinate of origin of the measurement coordinate system is determined by dividing the line joining the mid points $P_{m12}$ and $P_{m34}$ in the ratio 438:622. Points $P_{m12}$ and $P_{m34}$ are the mid points of measured points $P_{m1}$-$P_{m2}$ and $P_{m3}$-$P_{m4}$ respectively. For convenience each axis of the coordinate system is defined by a unit vector along the axis represented by its direction cosines. The measurement coordinate system is represented as given below.

$$\text{X-axis}: X_m = [u_{mx}, u_{my}, u_{mz}] \tag{10}$$

$$\text{Y-axis}: Y_m = [v_{mx}, v_{my}, v_{mz}] \tag{11}$$

$$\text{Z-axis}: Z_m = [w_{mx}, w_{my}, w_{mz}] \tag{12}$$

$$\text{Origin}: C_m = (T_{mx}, T_{my}, T_{mz}) \tag{13}$$

The Parameters of this coordinate system are used as initial input parameters for the simplex search process.

Dimensional error between the design and measured points are estimated during each iteration for given parameters of the coordinate system. If sum of the errors is above specified convergence value, the iteration process is continued. When the value reaches the convergence value, the iteration process is stopped and the parameters of the coordinate system during the final iteration are considered as the measurement coordinate system. For this coordinate system the sum of the deviations of the measurement points from design points on sub frame ($P_{m1}$ to $P_{m4}$) will be minimum. The dimensional errors in the position of the points on the front chassis module are evaluated with reference to this coordinate system. Various steps involved in analysis of measurement data are shown in Fig. 6.

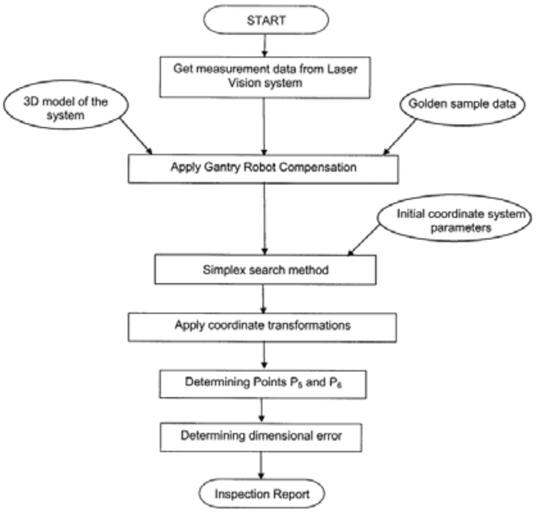

**Fig. 6** Steps involved in inspection and evaluation of front chassis module

### 5.2 Coordinate transformations

It is an usual practice in machine vision and non contact inspection systems to map the measurement and design points using 3 D coordinate transformations so that the dimensional errors can be obtained by direct comparison (Ramesh et al., 2000).

The design coordinate system can be represented as

$$\text{X-axis}: x_d = [u_{dx}, u_{dy}, u_{dz}] \tag{14}$$

$$\text{Y-axis}: y_d = [v_{dx}, v_{dy}, v_{dz}] \tag{15}$$

$$\text{Z-axis}: z_d = [w_{dx}, w_{dy}, w_{dz}] \tag{16}$$

$$\text{Origin}: C_d = (T_{dx}, T_{dy}, T_{dz}) \tag{17}$$

The measurement coordinate system can be transferred to the global coordinate system with origin (0, 0, 0) using transformation matrices shown in equation 18. If $T_{mx}$, $T_{my}$ and $T_z$ are the coordinates of the origin of measurement center, then the translation of the coordinates of measurement points to the global origin is carried out using the translation matrix $T_m$. The measurement axes can be rotated to coincide with global axes using the rotation matrix $R_m$.

$$\mathbf{T}_m = \begin{bmatrix} 1 & 0 & 0 & -T_{mx} \\ 0 & 1 & 0 & -T_{my} \\ 0 & 0 & 1 & -T_{mz} \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad \mathbf{R}_m = \begin{bmatrix} u_{mx} & u_{my} & u_{mz} & 0 \\ v_{mx} & v_{my} & v_{mz} & 0 \\ w_{mx} & w_{my} & w_{mz} & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{18}$$

The transformations from global coordinate system to the design coordinate system are done by using the translation and rotation matrices shown in Equation 19.

$$\mathbf{T}_d=\begin{bmatrix}1 & 0 & 0 & -T_{dx}\\ 0 & 1 & 0 & -T_{dy}\\ 0 & 0 & 1 & -T_{dz}\\ 0 & 0 & 0 & 1\end{bmatrix}\quad \mathbf{R}_d=\begin{bmatrix}u_{dx} & v_{dx} & w_{dx} & 0\\ u_{dy} & v_{dy} & w_{dy} & 0\\ u_{dz} & v_{dz} & w_{dz} & 0\\ 0 & 0 & 0 & 1\end{bmatrix} \tag{19}$$

### 5.3 Evaluation of points P5 and P6 on the lower arm

After determining and mapping the measurement and design coordinate systems, the dimensional accuracy of points $P_5$ and $P_6$ is verified. To obtain the x and y coordinates of the measurement points a circle is constituted from the inspection data obtained at three points $P_{m51}$, $P_{m52}$, $P_{m53}$ for point $P_{m5}$ and $P_{m61}$, $P_{m62}$, $P_{m63}$ for $P_{m6}$ as explained in Section 3. In order to make direct comparison of the dimensions with the design specifications, the dimension of the points $P_5$ and $P_6$ is obtained on the above mentioned circle when $Z=-78.2$. The constructed using three points $P_{m51}$, $P_{m52}$, $P_{m53}$, plane $PL_2$ with $Z=-78.2$ and the point of intersection $P_{m5}$ is shown in Fig. 7. Similarly using points $P_{m61}$, $P_{m62}$ and $P_{m63}$, the location of point $P_{m6}$ can be determined. After determining the position of points the dimensional errors can be estimated by comparing them with the design specifications.

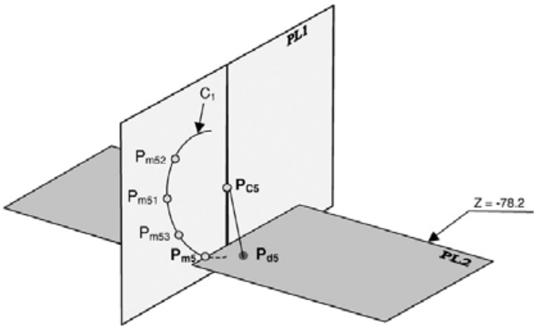

**Fig. 7** Determination of points $P_5$ and $P_6$ on lower arm

## 6. Experimental Results

The design specifications for the six inspection points on the front chassis module (shown in Fig. 4) are given in Table 1. The measurement data taken for golden sample using a CMM and the present laser vision system is presented in Table 2. The required parameters of 3D model are obtained by Monte Carlo simulation technique using the golden sample measurement data obtained by CMM and laser vision systems. The optimal parameters determined by simulation are shown in Table 3. Some of the parameters like ball screws pitch errors coefficients $K_{X1}$, $K_{X2}$, $K_Y$, $K_Z$ can be identified independently by different methods. For other parameters more precise initial boundaries estimation can lead to more accurate results.

Sample measurement data obtained for laser vision system for the front chassis module is given in Table 4. Points $P_{m1}$ to $P_{m4}$ are used for determining the initial coordinate system. The simplex search technique is used for optimal coordinate system with minimum possible deviation between the design and measurement points. All the measurement points $P_{m1}$ to $P_{m4}$ and points $P_{m51}$, $P_{m52}$, $P_{m53}$ corresponding to $P_{m5}$ and $P_{m61}$, $P_{m62}$, $P_{m63}$ corresponding to $P_{m6}$ are transformed to design coordinate system using coordinate transformations given in section 5.2. The location of points $P_{m5}$ and $P_{m6}$ are determined using the method explained in section 5.3.

**Table 3** 3D model parameters obtained by simulation using Monte Carlo method

| Axis / Parameter | X | | Y | Z |
|---|---|---|---|---|
| Origin X2 shift **h**, mm | 0.206945 | | −1.257603 | −2.472651 |
| X2 angle $\boldsymbol{\theta}$, ° | 0.004241 | | 89.996520 | 89.997580 |
| Z angle $\Psi$, ° | 90.056710 | | 89.618786 | 0.385410 |
| Distance **s**, mm | — | | 302.385254 | 23.581665 |
| Ball screw coefficient **K** | X1 | X2 | 1.000232 | 0.999656 |
| | 1.000137 | 0.999828 | | |

**Table 4** Sample measurement data obtained from the coordinates of laser vision measurement system

| Point No. | | x (mm) | y (mm) | z (mm) |
|---|---|---|---|---|
| $P_{m1}$ | | 1187.967 | 386.976 | 393.078 |
| $P_{m2}$ | | 1187.764 | 1022.802 | 392.898 |
| $P_{m3}$ | | 127.962 | 1199.003 | 297.049 |
| $P_{m4}$ | | 128.307 | 211.218 | 296.976 |
| $P_{m5}$ | $P_{m51}$ | 734.206 | 1428.692 | 468.118 |
| | $P_{m52}$ | 734.206 | 1424.851 | 419.311 |
| | $P_{m53}$ | 734.206 | 1424.851 | 516.926 |
| $P_{m6}$ | $P_{m61}$ | 734.392 | 20.1416 | -468.307 |
| | $P_{m62}$ | 734.392 | 16.300 | -419.499 |
| | $P_{m63}$ | 734.392 | 16.300 | -517.114 |

In the present work results of measurement data processed with and without applying the compensation for installation errors are compared. The results obtained using the proposed algorithm for a sample data before and after applying the 3D compensation are presented in Table 5. The absolute deviation of these coordinates with that of design specifications are estimated as shown in Table 6. It is observed from the results that the deviation of the points from the design specifications is significantly decreased by applying the 3D compensation introduced in the present work. For instance, the maximum deviation for the data without applying compensation is 1.230, where as that with compensation is 0.700.

**Table 5** Coordinates of points after transformation

| Point No. | Without compensation | | | With compensation | | |
|---|---|---|---|---|---|---|
| | x | y | z | x | y | z |
| $P_{m1}$ | 437.966 | 318.022 | −3.078 | 437.952 | 317.963 | −3.093 |
| $P_{m2}$ | 437.764 | −317.802 | −2.898 | 437.963 | −318.009 | −2.992 |
| $P_{m3}$ | −622.038 | −494.003 | 92.951 | −622.026 | −494.125 | 93.043 |
| $P_{m4}$ | −621.693 | 493.782 | 93.024 | −621.868 | 493.889 | 93.217 |
| $P_{m5}$ | −15.793 | −723.692 | −78.200 | −15.489 | −724.568 | −78.2000 |
| $P_{m6}$ | −15.607 | 725.13 | −78.200 | −15.698 | 724.600 | −78.2000 |

**Table 6** Results of dimensional error evaluation

| Pt. No. | Absolute Deviations (mm) | | | | | |
|---|---|---|---|---|---|---|
| | Without compensation | | | With compensation | | |
| | x | y | z | x | y | z |
| $P_{m1}$ | 0.034 | 0.022 | 0.078 | 0.048 | 0.037 | 0.093 |
| $P_{m2}$ | 0.236 | 0.198 | 0.102 | 0.037 | 0.009 | 0.008 |
| $P_{m3}$ | 0.038 | 0.003 | 0.049 | 0.026 | 0.125 | 0.043 |
| $P_{m4}$ | 0.307 | 0.218 | 0.024 | 0.132 | 0.111 | 0.217 |
| $P_{m5}$ | 0.493 | 0.208 | 0 | 0.189 | 0.668 | 0 |
| $P_{m6}$ | 0.307 | **1.230** | 0 | 0.398 | **0.700** | 0 |

## 7. Conclusions

To achieve better accuracy and precision and to eliminate installation errors in laser vision measurement system, the calibration of the system is required. A unique compensation method based on 3D geometric model of the gantry system is presented in this paper. The parameters required for the 3D model of the gantry are obtained by Monte Carlo simulation using the inspection data of golden sample obtained using CMM and the present system. The deviations of the points on the chassis module are reduced by applying the compensation based on the 3D model proposed in the present work. This method proved very effective in reducing the installation errors in the laser based measurement system. Additionally, the performance of the system can be further improved by using precisely measured parameters in the 3D model.

The software based on simplex search technique is efficient and powerful in analyzing the inspection data by minimizing error in setting measurement coordinate system. This method is simple and easy to implement. When the initial parameters are given appropriately for simplex search, the optimal solution can be arrived in a short time, with less number of iterations. The results of measurement data analyzed with and without compensation are compared in the present work. Better and reliable results are obtained by applying compensation to the measurement data. It is evident from the present work that the performance of an inspection system can be significantly improved by combining the techniques of hardware compensation and efficient software. Precise assessment of the parts reduces the risk of rejection of good parts. The present system can be can be effectively used for 100%, on-line inspection of the automobile components.

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