

METROLOGY NORWAY SYSTEM – AN ON-LINE INDUSTRIAL PHOTOGRAMMETRY SYSTEM

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SUMMARY:

Metrology Norway System is an industrial photogrammetry system based on high resolution CCD cameras measuring coordinates of laser spots or light emitting diodes. The system is a true on-line measurement system presenting results immediately, point by point. The Light Pen, a mechanical probe, turns the system into a 'Hand-Held Coordinate Measurement Machine'. A CAD module allows all measurements to be related directly to the CAD model as Closest Point Deviations. The system has a broad range of applications in automotive and aerospace industry. The paper presents the metrology concept, and focuses on applications with examples from Volvo, Saab Aircraft Division, and Fiat.

KEYWORDS: CAD/CAM, Close-range, Industrial, Real-Time, 3-D

1 INTRODUCTION

The Metrology Norway System (MNS) presents a totally new concept for industrial metrology. It is a system that provides accuracy for most metrological applications, yet includes the features of rapid data collection over a large volume as well as system portability, which allows for extreme system versatility for a number of applications.

The system is developed in close cooperation with Volvo Car Corp., Department of Production Technology. This ensures that the system is tailored to the industrial needs.

The system is based upon specially manufactured and calibrated CCD cameras. The one-time factory calibration converts each camera into an ideal on-line photogrammetric camera. MNS measures the spatial (XYZ) coordinates of special infrared Light Emitting Diodes (IR LEDs), or alternatively, points of reflected IR laser light.

This paper focuses on the measurement concept, as well as applications. The accuracy of the system is discussed in detail by Pettersen (1992).

A new measurement concept, making 3D measurements using only one CCD camera, is discussed by Aamdal (1992).

2 THE MNS CONCEPT

2.1 Photogrammetry

MNS is basically a photogrammetry system, based on high resolution CCD cameras (Videk MegaPlus). The cameras are interfaced to a VME based computer making high performance signal analysis, giving a sub pixel resolution of 0.01 pixel.

To obtain an optimum accuracy, and to make the system easy operational, the cameras are factory calibrated. This calibration process involves a complete mapping of the

entire sensor, giving a detailed description of lens distortions, sensor geometry and sensor defects. The result of the camera calibration, i.e. the interior orientation of the camera, is stored in the system computer, and is used to correct each observed image coordinate to that of the 'ideal' photogrammetric camera. The calibration method is a unique proprietary technique developed and patented by Metronor, and will not be described in further detail in this paper.

The factory calibration allows the camera to be used at any location without any calibration in the measurement setup. A simple set up procedure is needed to determine the relative position of the two cameras and the object of interest:

- The cameras are easily aimed towards the object such that the fields of view of the cameras overlap, covering the volume which contains or will contain the object to be measured. The user is able to see the actual images from the cameras at the computer monitor.
- The exterior orientation of the cameras, i.e. their relative position and orientation, is determined by the use of a Reference Bar as shown in fig. 1. The Reference Bar contains several infrared (IR) LEDs embedded in a bar made of the alloy Invar and is connected to the MNS System Console via a multi-purpose cable. The Reference Bar is aimed so that both cameras are able to view the LEDs. Pressing a button located on the end of the Bar causes a measurement to be taken. The user then changes the orientation of the bar, and the button is pressed again. For optimum results, measurements are taken throughout the entire intended measurement volume. This allows for maximum redundancy in the initialization routines.
- The camera positions and orientations are then automatically calculated using the method of bundle adjustments. This essentially is a least squares analysis to fit the given distances between the light sources in all bar positions to the calcula-

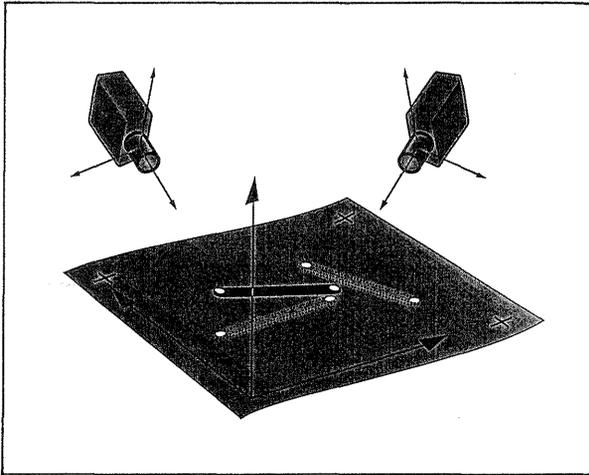


Fig. 1. Camera Setup and Exterior Orientation

ted positions and orientations of the cameras. The calculation routine displays the maximum and mean deviation from the certified length. The bundle adjustment algorithm does not require initial values for any of the parameters to be determined.

- The results of the exterior orientation defines a global coordinate system. To relate all measurements to a local coordinate system, reference points are needed, having well known local coordinates. Two options are given: three reference points given by their x, y and z coordinates, or a maximum of six points given as a 3 - 2 - 1 system. A 3 - 2 - 1 reference system may as an example be given as three points defined by their z-values, two points by their y-values, and the last point by its x-value. The reference points are typically plane surfaces or holes. A simple tool used to measure reference points is the Light Pen, as described below.

The system includes a UNIX based workstation, dedicated to application specific software, and user interface.

2.2 The Light Pen

MNS introduces the patented Light Pen (fig. 2), which makes MNS become a transportable Coordinate Measurement Machine (CMM) for applications requiring accuracies in the order of 0.1 mm. The Light Pen is a device allowing the user the freedom to digitize any selected point on an object. The user places the tip of the Pen on the selected point, ensures that the cameras can see the LEDs, and presses an exposure button on the Pen. The coordinates of the Light Pen tip are immediately presented at the computer display.

The Light Pen contains three LEDs whose coordinates in the Light Pen's local coordinate system are well-known. With this knowledge of the Light Pen's geometry, MNS easily calculates the spatial coordinates of the Pen's stylus tip by measuring the spatial coordinates of the three LEDs on the Pen.

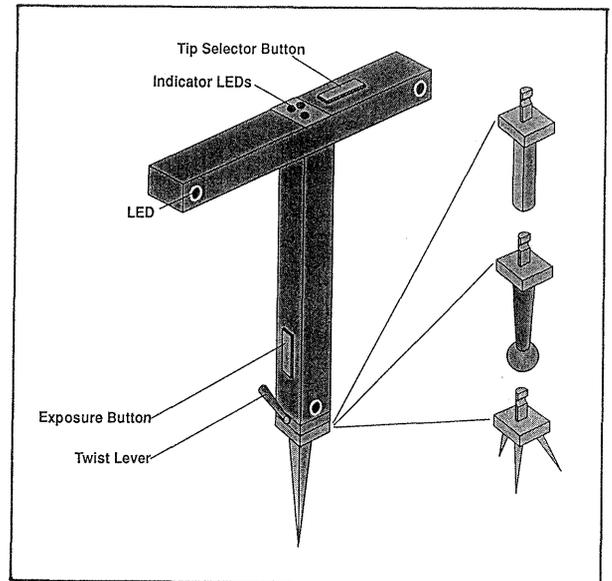


Fig. 2. Light Pen

The interchangeable pen tip tool is analogous to a Coordinate Measurement Machine's probe/stylus combination. Each tool has been previously calibrated, either by Metronor or the user, and its stylus tip coordinates with respect to the Pen's local coordinate system are stored in MNS. The user is free to create unique styli to allow measurements in difficult to reach areas. To take a measurement, the cameras need only to see the LEDs and not the actual tip of the Pen. For instance, if the user wants to measure points underneath a surface of an object, a stylus could be bent into the shape of a hook.

The Light Pen enables measurements of physical features like:

- * Single XYZ Coordinate
- * Distance between two points
- * Holes - diameter and center coordinates
- * Spheres - diameter and center coordinates
- * Flush - the distance and relative angle between two surfaces
- * Gap - the gap (distance) between two lines or edges

The light pen is an important tool for measuring the coordinates of reference points.

2.3 Laser spot projection

Various laser-spot projection systems are also available. The Laser Projector Gun is an ideal tool for measurements involving soft or foamy materials (i.e. those found in automobile interiors) that would deform if measured by conventional contact methods. As MNS measures the spatial coordinates of spots of infrared (invisible to the human eye) light, the Laser Projector Gun projects two visible lasers, as well as the invisible laser that is measured. The visible lasers are necessary for determining the correct focus and target point, as it is essential that the spot is in optimum focus to reduce or eliminate the effects of speckle.

Also available are single spot lasers which are simply laser diodes that project a single spot to be measured. The user individually mounts and aims these lasers to measure discrete points on an object's surface.

A dual-axis laser scanner unit is a stand-alone product that can be integrated under MNS control. The unit projects a single point beam of infrared laser light onto the object of interest. MNS measures the spatial coordinates of this point of diffusely reflected laser light. Contained inside the unit are a laser source and two mirrors whose angular orientation are accurately controlled. The beam reflects off of these positioning mirrors, which direct the spot to the intended measurement location on the object. The 'flying spot' scanner receives mirror positioning commands from MNS. The scanner also incorporates a necessary laser beam autofocus function.

2.4 CAD interface

MNS is capable of relating the measurement data to the nominal CAD model of the particular object. This is performed through a Closest Point (normal to the surface) comparison of the physically measured data to its corresponding location on the nominal CAD surface.

The data exchange with the CAD system is based on the use of the standard geometry data exchange format VDA-FS. The VDA-FS model is downloaded through an Ethernet link and stored locally in the MNS workstation. MNS then converts this VDA-FS model into a B-spline representation of the surface.

During Closest Point measurements the CAD wire-frame appears in a window on the high resolution color monitor in a user-selectable orientation. Once a measurement is taken, the XYZ coordinate as well as its Closest Point to the nominal CAD reference is displayed numerically, and graphically on the CAD wire-frame.

The Closest Point software can handle single point measurements (light pen applications) as well as simultaneous measurement of multiple points (laser spot applications).

2.5 Six degrees of freedom software

The Six Degrees of Freedom Software allows the user to measure the position and orientation of one object with respect to the position and orientation of another object, or any convenient Base Reference System.

3 ACCURACY

3.1 Resolution

The sensor has a resolution very close to 0.01 pixel (1σ), due to a thorough optimization of signal to noise ratio as well as algorithms.

In a camera setup covering a cubic measurement volume of $1.0 \times 1.0 \times 1.0 \text{ m}^3$, and the two cameras set up to give

optimum intersection angles, this corresponds to a spatial resolution of better than $40 \mu\text{m}$ ($U95$ i.e. 2σ) all over the measurement volume. The resolution is better in the vertical direction due to redundancy.

3.2 Absolute geometric accuracy

The most important feature of the system is to obtain high geometric accuracy all over the measurement volume. The factory calibrated cameras, and the utilization of a certified reference bar to determine the exterior orientation of the cameras, ensures accurate and reliable results in any setup.

The absolute accuracy is specified according to standards used for conventional Coordinate Measurement Machines, e.g. the German norm VDI/VDE 2617. According to this specification the accuracy of the system can be defined by the 'Uncertainty of Length Measurements' described by the formula:

$$U_{95}(3D) = 0.08 + \frac{L}{15000} \text{ [mm]}$$

where L is the distance to be measured. This formula is based on light pen measurement, and means that whatever position a reference length has in the measurement volume, its length will be determined within the specified accuracy with 95 % confidence.

Further discussion of accuracy is given by Pettersen (1992).

4 APPLICATIONS

MNS is a general geometry measurement system dedicated for industrial applications. Its versatility and flexibility offers solutions to a large number of measurement problems:

4.1 Quality Control of Stamped Parts (Off-line QC)

Ref.: Saab Aircraft Division.

One of the major applications of the Metrology Norway System is the measurement of manufactured surfaces, e.g. aircraft components made from composite materials or stamped automobile parts (fig. 3). After a die is changed on a stamping line, the first few parts off the stamping line are examined to quantify the deformations that exist in the part relative to its ideal shape (First-Off stamped part inspection). MNS is a fast and effective method in this application, eliminating the need for expensive reference fixtures.

Applying the Light Pen for Closest Point measurements enable a very fast mapping of any deviations from the CAD model.

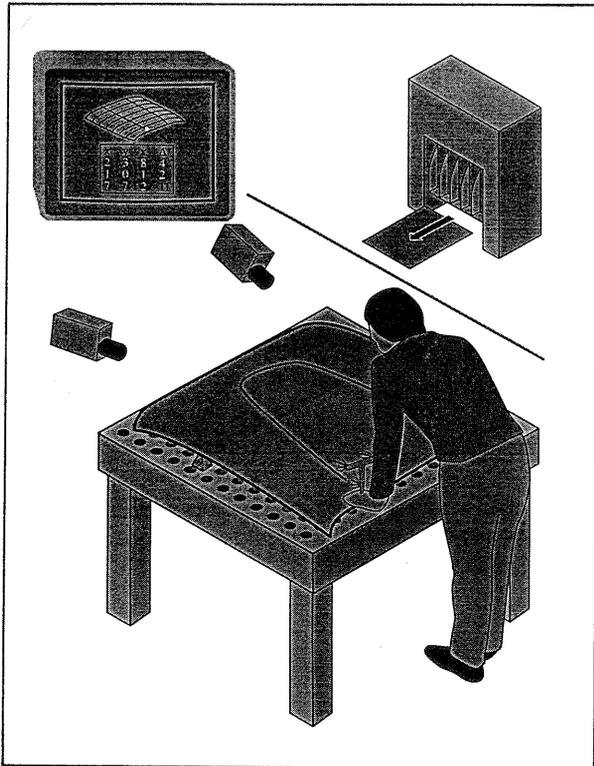


Fig. 3. Off Line Quality Control

4.2 Verification of Production Cells

Ref.: Volvo Car Corporation.

To ensure high product quality from e.g. a car body production line, it is essential that the jigs and fixtures – the steering or indexing pins, holes, brackets and clamps are in their exact positions. Quality problems may arise from wear and tear, or by events such as a robotic collision which drastically alters the position of a bracket.

MNS is ideally suited for this application. First of all it is easily transported to the production cell, and since the cameras can be freely positioned, it becomes quickly operational. The light pen is the essence of simplistic operation. By touching the cell reference points, MNS automatically creates the transformation matrix that allows it to measure in the Car coordinate system. If a CAD model of the cell exists, deviations from nominal values are instantly available.

4.3 Measurement of Displacements and Deformations

Ref.: Centro Ricerche Fiat.

MNS also serves as a nonobtrusive technique in measuring relative spatial displacements. This is useful for quantifying deformations as a function of various applied forces. One application is the verification and calibration of Finite Element Method (FEM) computer models of

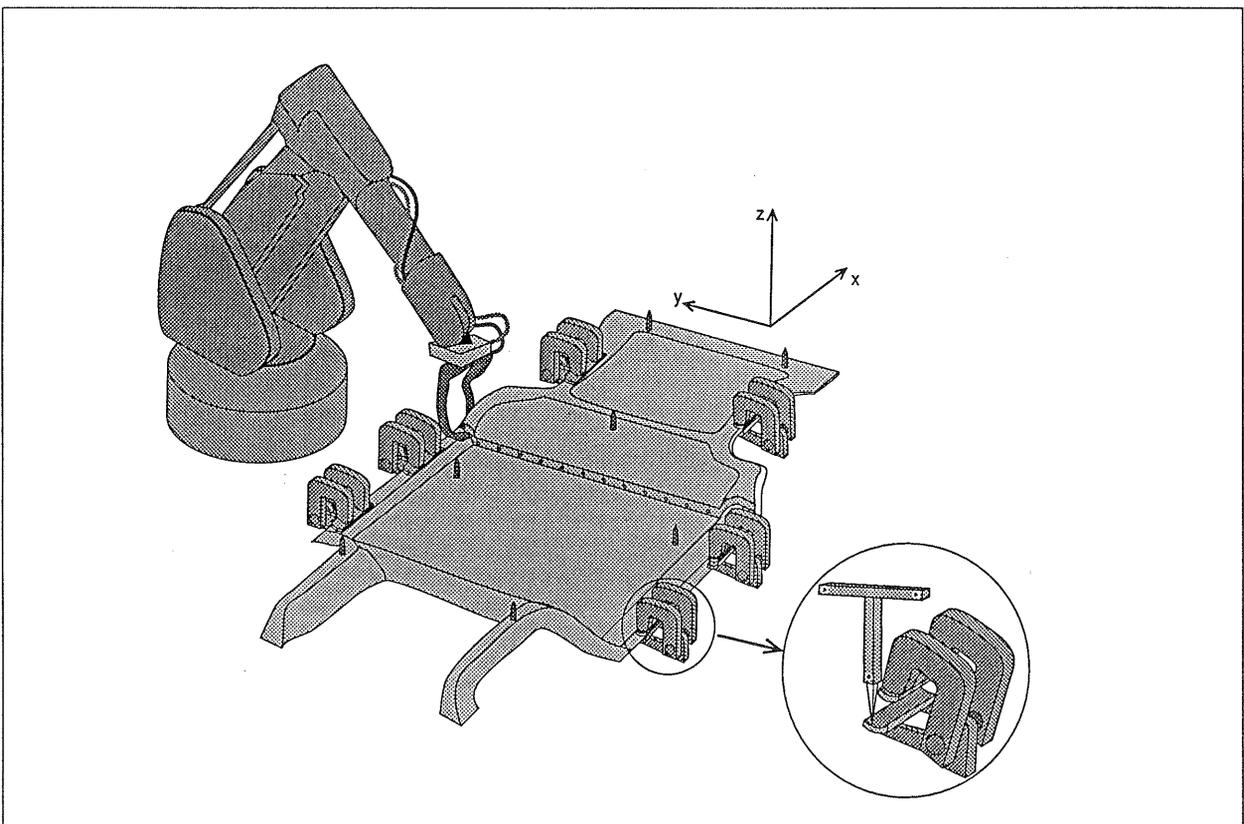


Fig. 4. Geometric Verification of Fixtures and Clamps

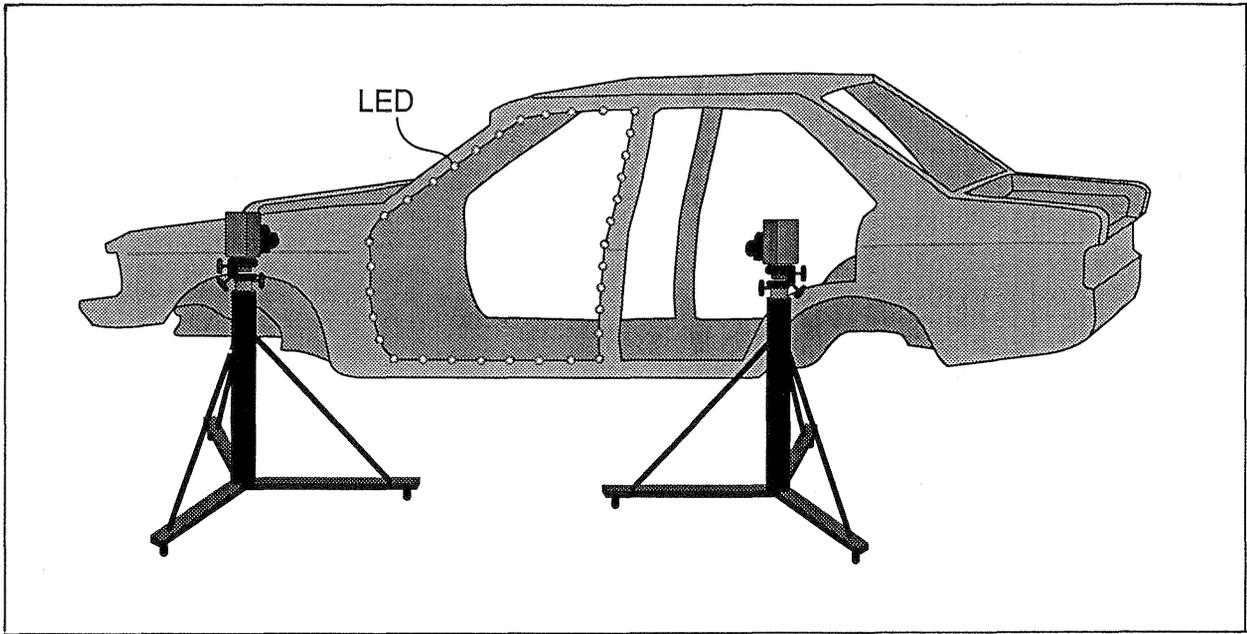


Fig. 5. Measurement of Physical Displacements

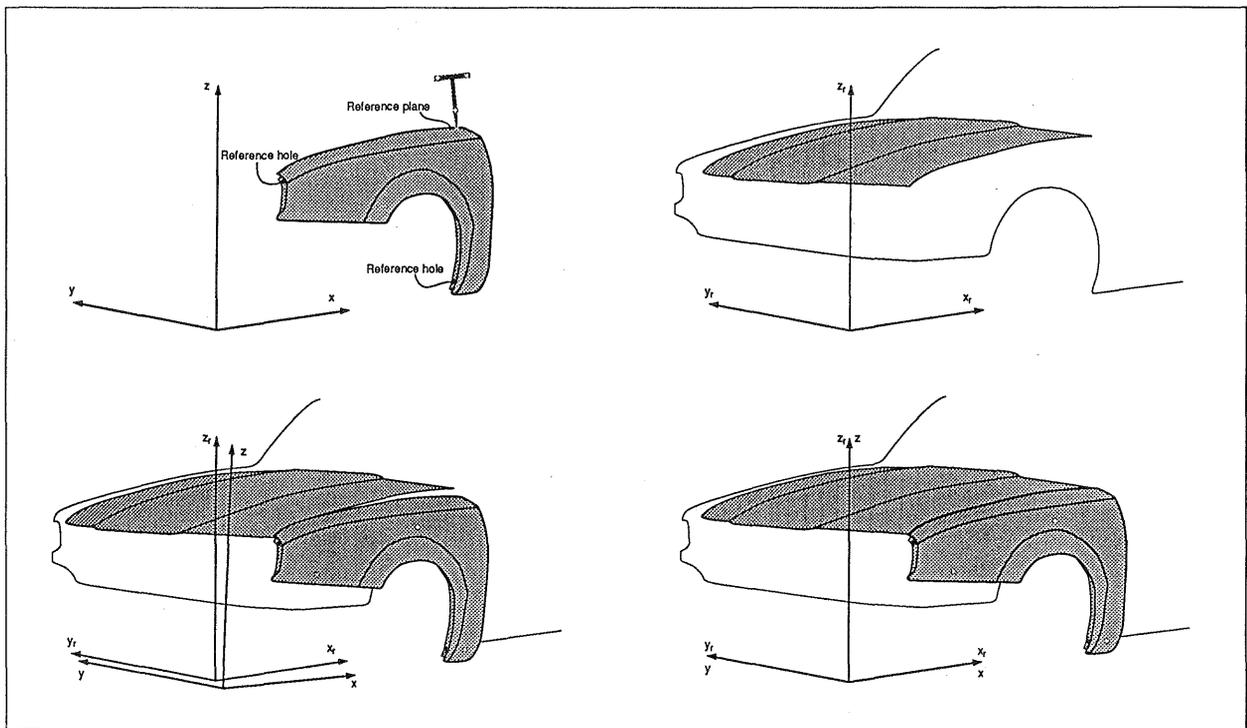


Fig. 6. Measurement of Object Position and Orientation

unitized car bodies. The example shown in fig. 5 is that of measurement of door line variation of a unitized car body, as the body is subjected to various forces. Other applications are found in collision testing.

Reusable LED packages are glued onto the subsystem in the selected locations. MNS simultaneously measures the displacement of each individual LED at a maximum

measurement frequency of 2 Hz. The measurements are initiated by the operator through the MNS keyboard, or externally triggered by a TTL signal to synchronize to the applied force.

4.4 Prototype Assembly / Object orientation

MNS has the capability to measure the position and orientation of objects relative to any user-defined Base Reference System. The example illustrated in fig. 6 is the determination of the position and orientation of a fender during prototype assembly. The reference system shall be the Car Coordinate System.

Three LEDs are attached to the fender. MNS is able to instantly measure and store the location of these LEDs with respect to the Fender Coordinate System which is defined by reference points as described in section 2.1. These LEDs now act as new "help" reference points for the assembly process.

Turning to make measurements relative to the Car Coordinate System (by the use of new reference points), MNS is able to determine the fender subassembly's actual position and orientation relative to the Car Coordinate System by monitoring the LEDs.

This measurement technique has several applications in aerospace industry, e.g. wing assembly, control surface calibrations etc.

This feature can be used for on-site robotic training. The position and orientation of the robot arm can be compared to its nominal values, and thus be used to make a calibration table for the robot.

4.5 Digitization of Free Form Surfaces

MNS has the capability to rapidly digitize an entire mode car body through the utilization of the Laser Scanner (Section 2.3) as shown in fig. 7.

The Laser Scanner steps a spot of infrared laser light across the surface of the Car Body. The linear increment distance (distance between individual data points) may be defined by the user or MNS may adapt the increment to the curvature of the object. Typical data acquisition rate will be slightly under 2 measurements per second, or approximately 5000 data points per hour.

The user is free to locate the Laser Scanner in the optimum position depending on the size and shape of the object. MNS can compute the location of the scanner, similar to the photogrammetric initialization used for determining camera locations by issuing predefined angular commands to the scanner mirrors and measuring the corresponding XYZ locations of the spot on the car body.

The Light Pen proves to give valuable additional information by digitizing feature lines and discontinuities (such as holes and edges).

In wind tunnel testing a physical model is modified to optimize its aerodynamic design. It is important to document all steps in the modification process. Thus, a fast measurement procedure is needed. The measured coordinates can be applied to update the CAD model.

A system including a laser scanner can function as a programmable CMM for quality control. In such an application the scanner movements will be programmed from the CAD model.

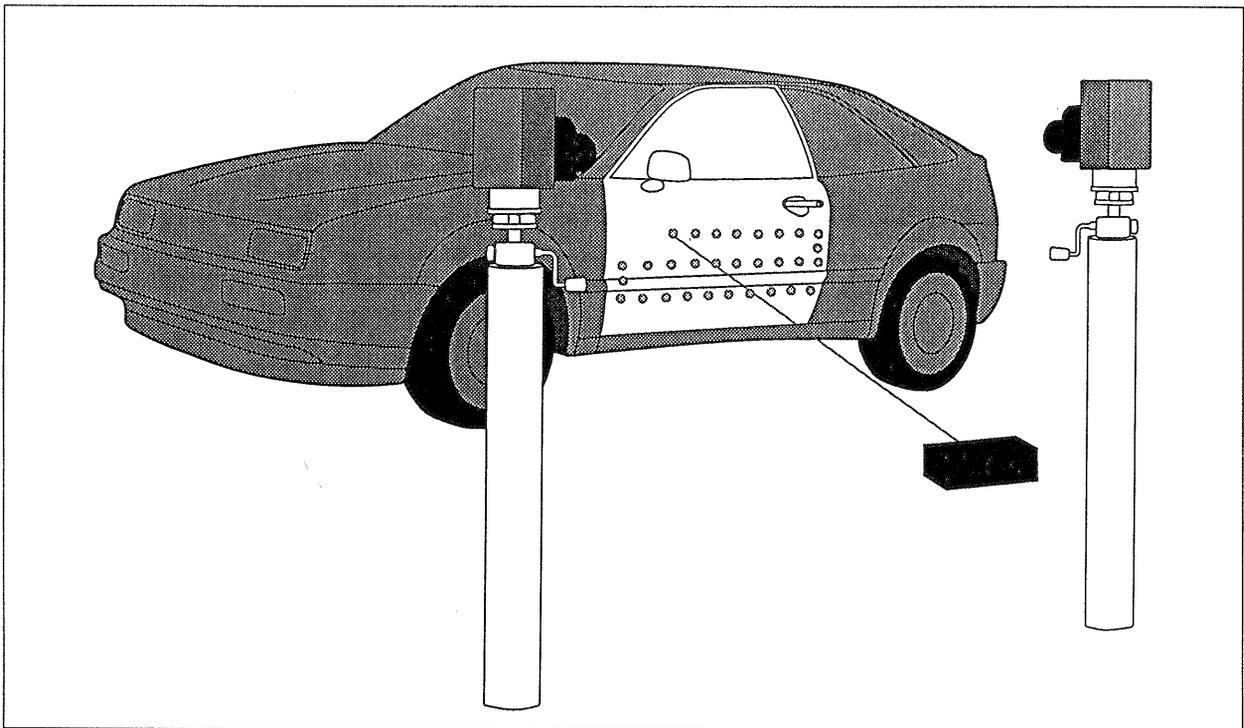


Fig. 7. Digitizing of Car Body

4.6 In Line Quality Control of Stamped Parts

Applying a large number of single spot lasers projected onto a surface, MNS can map any deviation from the CAD model within a few seconds.

5 CONCLUSIONS

MNS is the only on-line photogrammetry based coordinate measurement system fulfilling the accuracy specifications given by the automotive industry for car body measurements. This high accuracy, as well as the portability of the system, makes it into a unique tool for a number of applications beyond the reach of present coordinate measurement systems.

References:

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- + Aamdal, K., Single camera system for close range industrial photogrammetry, Presented paper, Commission V, XVII Congress of ISPRS, Washington 1992