METROLOGY NORWAY SYSTEM - OPTIMUM ACCURACY BASED ON CCD CAMERAS

Alf Pettersen, Tech. Mgr., Metronor AS

(P.O.Box 238, N-1360 Nesbru, Norway)

Commission V

SUMMARY:

Metrology Norway System is an on-line industrial photogrammetry system based on high resolution CCD cameras measuring coordinates of laser spots or light emitting diodes. A patented camera calibration technique, as well as high performance signal analysis ensures accuracy of 0.1 mm within a measurement volume of 1.0 x 1.0 x 1.0 m^3. The Light Pen, a mechanical probe, turns the system into a "Hand-Held Coordinate Measurement Machine", and allows the system accuracy to be verified according to standards for Coordinate Measurement Machines. The paper discusses accuracy limitations, verifications, and the result of accuracy tests.

KEYWORDS: Accuracy, Calibration, Close-range, Industrial, 3-D

1 INTRODUCTION

The use of CCD camera based photogrammetry systems for industrial applications has so far been limited by low accuracy. As an example the automotive industry has a general accuracy requirement of 0.1 mm for car body measurements.

The Metrology Norway System (MNS) presents a totally new concept for industrial metrology. It is the first, and so far the only, fully on-line photogrammetric system having the necessary accuracy to be accepted in the automotive and aerospace industry.

This paper focuses on the accuracy of the system, and the reliability of the measurements. A discussion of the measurement concept as well as applications is given by Pettersen (1992).

2 SYSTEM DESCRIPTION

2.1 Cameras and calibration

MNS is based on high resolution CCD cameras (Videk MegaPlus). MNS measures the spatial (XYZ) coordinates of special infrared Light Emitting Diodes (IR LEDs), or alternatively, points of reflected IR laser light.

To obtain optimum accuracy, and to make the system easy operational, the cameras are factory calibrated. This one-time calibration process which turns the camera into an "ideal" photocrammetric camera involves a complete mapping of the entire sensor, giving a detailed description of lens distortions, sensor geometry and sensor defects. The calibration method is a unique, proprietary technique developed and patented by Metronor, and will not be described in further detail in this paper.

2.2 Exterior orientation

The exterior orientation of the two cameras of the standard MNS, i.e. their relative position and orientation, is determined by the use of a Reference Bar as illustrated in figure 1. The Reference Bar contains several infrared (IR) LEDs embedded in a bar made of the alloy Invar. The Reference Bar is aimed so that both cameras are able to view the LEDs. The Reference Bar LED positions are measured for several bar locations throughout the entire intended measurement volume.

The camera positions and orientations are calculated using the method of bundle adjustments.

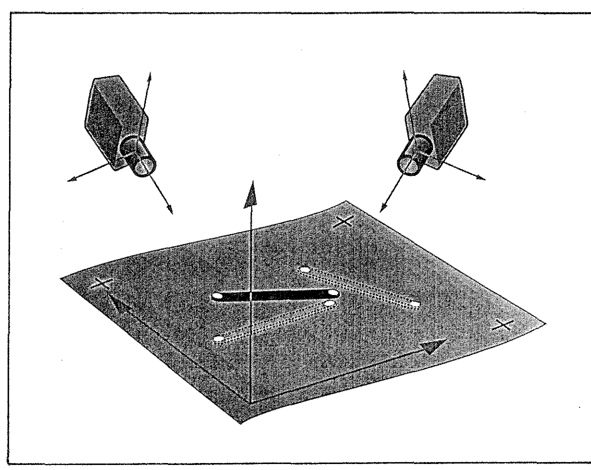

Fig. 1. Camera Setup and Exterior Orientation

2.2 The Light Pen

The Light Pen as shown in figure 2 is a mechanical device containing 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. This tool makes MNS into a transportable or "hand held" Coordinate Measurement Machine (CMM).

The Light Pen enables accuracy verifications according to CMM standards as described in chapter 6.3.

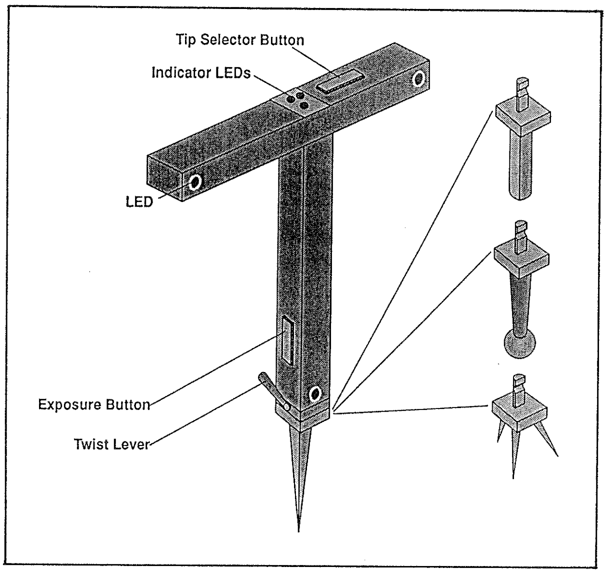

Fig. 2. Light Pen

3 RESOLUTION

The MegaPlus sensor resolution is 1350 x 1035 pixels, having 100 % fill ratio. The pixel size is 6.8 x 6.8 μm.

By the use of a thorough statistical analysis of the point image, a subpixel resolution of close to 0.01 pixel (1σ) is obtained. This high quality subpixel resolution is a result of:

-sensor and camera electronics quality,
-optical design, i.e. spot size optimization,
-signal to noise ratio optimization.

The reliability of the measurements at the sub-pixel level is strongly related to the use of unique and well defined light emitting diodes and laser sources. This overcomes the weakness of conventional techniques based on targets or object features, which may be very dependent on ambient light conditions.
The sensor resolution of 0.01 pixels projects into the object space to e.g. 0.01 mm in a field of view of 1.0 x 1.0 m^3.

4 ABSOLUTE, GEOMETRIC ACCURACY

Absolute geometric accuracy is ensured by the camera calibration which allows the camera to be considered as an "ideal" photogrammetric camera, i.e. the inner orientation of the camera is determined once and for all.

Untill now, no performance degradation has been observed. The longest periode of operation of a camera has been one year, including rough treatment in industrial environments. The validity of the camera calibration is checked at each new setup as explained in chapter 6.2.

5 APPLICATION DEPENDENCIES

5.1 Setup geometry

The resolution as measured in the object space is proportional to the dimensions of the measurement volume.

Generally, a two camera system always have a better accuracy vertically due to redundancy. In the horizontal plane the error distribution between width and depth depends on intersection angle as shown in figure 3. Reducing the intersection angles improves the width accuracy, but reduces the depth accuracy. This has to be taken into account when designing the camera setup. For alignment purposes (e.g. to check the straightness of an aircraft fuselage) the cameras should be mounted close together.

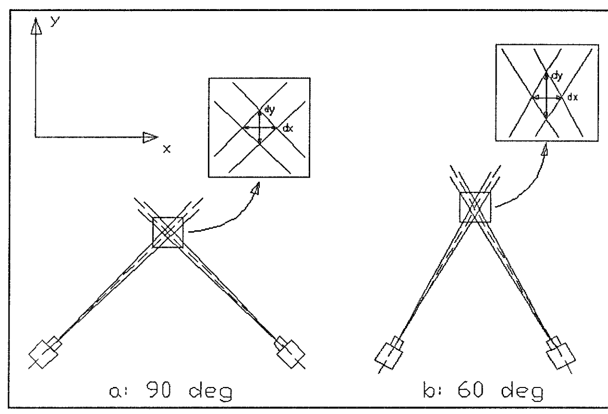

Fig. 3 Distribution of error in the horizontal plane.

Introducing a third camera could significantly improve the accuracy.

5.2 Light pen

The accuracy depends on:

- the size and shape of the Light Pen relative to the measurement volume,
- the distance from the pen tip to the light sources.

The standard MNS Light Pen has so far been T-shaped, having three light emitting diodes (LEDs).

A new light pen is developed, having a new geometry and 5 or 6 LEDs. To optimize the Light Pen to the application, Light Pens of different sizes should be used.

5.3 Laser applications

To achieve optimum accuracy for laser applications, the laser is focused to eliminate speckle problems. The accuracy may depend on the material, as diffuse reflection is required. Accurate measurements are demonstrated for difficult materials as unpainted steel, aluminum and black plastics.

6 ACCURACY VERIFICATION AND RELIABILITY

It is important for the user to get accurate and reliable measurements under realistic, industrial environments. The accuracy of MNS can be tested and verified by different methods as listed in the following chapters, either in dedicated laboratory setups, or as a part of the day to day operation. This guarantees the reliability of the measurement results.

6.1 Camera calibration

The camera calibration is a very thorough procedure, taking into account both global effects like lens distortions, and local effects on the pixel level. The entire sensor, each individual pixel is mapped to take care of pixel variations and defects.

The reference instrument used for camera calibration is traceable to The US National Institute of Standards and Technology.

6.2 On–site accuracy verification

The Reference Bar used for determination of the exterior orientation has a length that is certified to an accuracy of 3 μm. Each setup procedure is concluded with a display of the accuracy in this setup, i.e. how well the measured bar distances match the certified value.

Measuring the length of the Reference Bar at any chosen location at any time after an initialization is a verification that the calculated spatial camera positions and orientations are still correct. It is not possible to achieve correct distance readings at any arbitrary position within the measurement volume if any errors have occurred that influence the accuracy of the cameras or the camera setup.

At each Light Pen measurement the Light Pen geometry is checked against its nominal value. Any discrepancies, e.g. caused by accidentally moving a camera, will prevent the operator from making further measurements.

6.3 System test according to VDI guidelines

The light pen allows the system accuracy to be verified by methods used for CMM's, e.g. according to the German VDI guidelines (VDI/VDE 2617). **MNS is the only photogrammetry system having this feature.** This feature allows for full verification of 3D accuracy.

7 ACCURACY TEST RESULTS

Thorough accuracy verifications has been made as parts of the technical cooperation with Volvo Car Corp., and related to tests and deliveries to other customers.

The test results below are related to a setup geometry optimized to give a measurement volume of minimum 1.0 x 1.0 x 1.0 m^3. The camera intersection angle is 60 to 90 deg.

The test results are given as U_{95} values, i.e. 2σ.

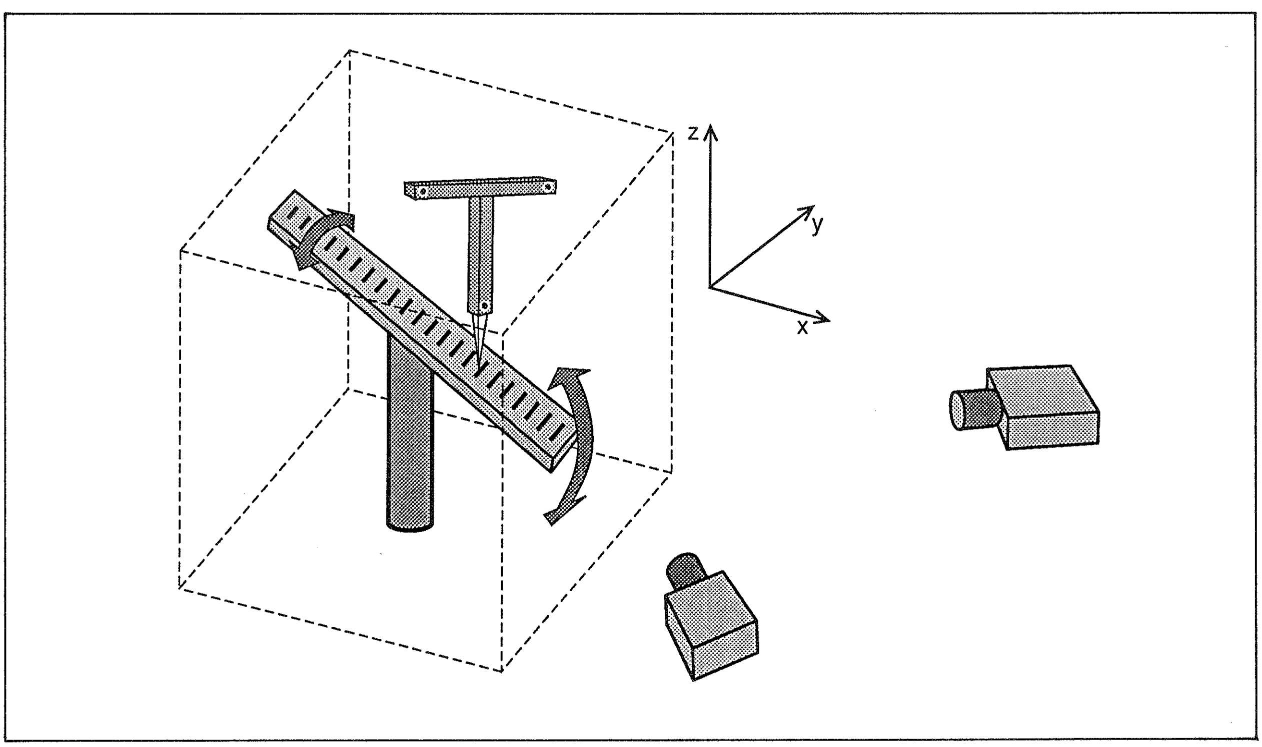

Fig. 4. Setup for Uncertainty of Length Measurement determination

7.1 Resolution – sub–pixel accuracy

A light emitting diode (LED) is mounted to a 3–axis translation stage in the center of the measurement volume. Three series of measurement were made, in each serie the LED is moved stepwise along one of the axes; steplength 0.05 mm, total translation 10 mm. At each step the position of the LED is measured. The measured data are fitted to a straight line of unity slope, and the deviations from linearity are calculated (U_{95}):

X–axis (depth)	31 μm
Y–axis (width)	22 μm
Z–axis (height)	20 μm

7.2 Repeatability of Light Pen measurements

The Light Pen is placed in the center of the measurement volume, and the repeatability of the Pen tip coordinates is checked by making 50 measurements in the same location. The Light Pen is hand held in its vertical orientation.

In the camera plane (horizontally):	0.077 mm
Vertically:	0.020 mm

The values for the camera plane are larger than the single LED resolution due to lack of redundant information from a Light Pen having only 3 LEDs. To overcome this problem, new Light Pens having 5 or 6 LEDs are developed.

7.3 Length measurements – geometric accuracy

A certified step gauge is placed along all four diagonals of the measurement volume as illustrated in figure 4. Maximum length: 1000 mm.

Accuracy:	0.05 mm
Uncertainty of measurements:	0.12 mm

The length measurements include statistical spread of single measurements at both ends of bar.

Compared to the results of chapter 7.2, the major contribution to the Uncertainty of Measurements is the Light Pen repeatability.

8 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.

Further improvements will be achieved by the new, improved Light Pen design.

References

Pettersen, A., Metrology Norway System – An on–line industrial photogrammetry system, Presented paper, Comission V, XVII Congress of ISPRS, Washington 1992.