STANDARDS AND REFERENCE ARTEFACTS FOR OPTICAL INSPECTION SYSTEMS

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Abstract

The use of optical systems for the dimensional inspection in industrial production (e.g. automotive, aeronautic) is steadily increasing. However, a thorough performance verification of such systems must still become more popular; now international standards have been published and the habit of verification may improve. The presentation will introduce to the key elements of prevailing standards. The basic rules for performance verification of Video CMMs and CMMs with fringe projection sensors and laser scanners, stand alone fringe projection and scanner systems will be discussed. In order to facilitate the verification according to prevailing standards, the author has developed a series of reference objects. These will be presented. A thematic excursion to some reference objects developed for the verification of photogrammetric and tomography systems will be made. For each measurement system the inherent problems and the developed solutions for the corresponding test artefacts will be analyzed.

Keywords: Performance Verification, Video CMM, Fringe Projection, Tomography, Multi Sensor

1. INTRODUCTION

Video based coordinate measuring machines (CMMs) are by numbers the most wide spread types of CMMs (yearly some 1600 measuring systems by one manufacturer alone). Many of these Video CMMs come as well with touch probes and sometimes more kinds of sensors, making them “multi sensor CMMs” with which the different features of parts can be measured all on one machine. The success of this type of measuring systems is in part due to the ever increasing share of miniaturization in consumer products (mobile phones, medical devices, sensors in automobiles). We find different accuracy ranges, from sub-µm accuracies to a few µm. Sizes range from the typical table top machine with 300 mm x 300 mm x 200 mm to several m of axis length (for example for flat screen inspection). Such systems have long lacked sufficient attention with respect to performance verification from manufacturers <u>and</u> users.

Particularly the automotive industry is since a couple of years about to revolutionize their quality inspection and process control by employing laser scanners and recently even more fringe projection systems in order to make measurements faster, more complete by a dense point coverage, and thus capable of verifying complex free form geometries with little effort, this goes hand in hand with the development of potent point cloud capable evaluation software.

Dental scanners (intra- and extra-oral) have until today almost not been verified for their metrological performance by commonly agreed procedures and with commonly agreed reference artefacts.

Besides optical non-contact measurement systems there is a relatively new area of industrial geometry inspection systems: tomography systems. As these systems are making progress with respect to accuracy and resolution, and as competition between manufacturers increases, performance verification has become a key issue. The first standards are in work now, and the first artefacts are on the market.

As far as artefacts are concerned, these have to have different properties for all these different measurement systems. It has been the goal of the developments undertaken by the author, to harmonize artefacts as much as possible to be usable for as many as possible classes of coordinate measuring systems: for example a multi sensor ball beam made without metal parts and only of carbon fiber composite and alumina ceramics is suited for tactile, video and tomographic measurement.

2. PERFORMANCE VERIFICATION OF VIDEO CMMS

2.1 International Standards

Since the publication of the respective international standard the **ISO 10360-7 (2011)** [1] we have a set of rules, harmonized with the rules for tactile CMM verification (ISO 10360-2 (2009) [2]), CMMs with optical scan heads (ISO 10360-8 (2013) [3]), multi sensor CMMs (ISO 10360-9 (2013) [4]) and surely there will be harmony with coming standards. National standards as VDI 2617-6 have served their purpose and accreditation bodies are eager to force the laboratories to change over to the recent ISO standards. Here an introduction to the basic rules of ISO 10360-7:

- the manufacturer states limits for a set of errors as we discuss in the following: “maximum permitted errors”.
- verification measurements on calibrated standards of length must be carried out in 7 lines in the volume of the CMM: 1 line parallel to each axis in the center of the not moved axes, 4 lines diagonally placed between the extremes of the measuring volume.
- If the CMM is not specified for a maximum allowed 3D-measurement error, then only 5 lines in the plane (XY-plane) orthogonal to the optical axis (Z-axis) are measured: including parallels to the axes and the diagonals between the extremes of the measuring volume in XY. In the latter case other additional tests apply to assure a maximum allowed squareness error between X and Z as well as Y and Z.
- In each of these lines 5 independent lengths must be measured, the biggest length must be at least 66% of the distance between the extremes of the measuring volume in the respective test line.

- All lengths must be per default measured in a bi-directional way, meaning that the effects of a “wrongly calibrated probe tip”, here better saying a “not properly compensated edge finder” (e.g. wrong threshold) would influence measured lengths. If center to center or left edge to left edge etc. measurements are made, then a calibrated line width must be measured additionally to the length standard (in the same direction as the respective measurement line) and the errors added to the observed length errors.
- All measurements must be repeated to yield 3 independent sets of 5 lengths each in each measurement line.
- The length measurement errors are evaluated as measured, temperature may not be compensated for manually. However, the calibration values of the reference artefact may be altered to correspond to the behavior of steel, if the artefact is of low thermal expansion material <u>and</u> the CMM has no internal temperature compensation. All errors must be smaller than the specified maximum length measurement error. As well the repeatability (range) of all the triplets of length measurements must be smaller than the maximum specified repeatability limit.
- Apart from the length error tests, a so called “probing test” is performed typically on a calibrated chromium-on glass circle. Simplifying slightly: the form error of the nearly perfect circle is measured with 25 measurement windows, which are per default to be positioned with the axes of the CMM around the circle periphery, and the result must be smaller than the maximum permitted form error.
- The uncertainty of the tests must be estimated and taken into consideration when making statements of compliance or non-compliance; if the supplier performs the tests, the uncertainty must be subtracted from the maximum permitted errors.

2.2 Artefacts

A couple of issues had to be solved with respect to the artefacts before tests according to this standard could be performed without too much “improvising”. Now there are the first laboratories accredited (ISO 17025 accreditations) according to this standard for video CMMs.

- Artefacts had to be developed which allow a “normal” or “shop floor” handling by the service or user staff. This particularly means there should not be glass edges protruding from the artefacts.
- These length standards should be available in the respective sizes of at least 66% of the maximum length of the verified measurement lines.
- If possible these length standards should be of low thermal expansion material to allow on high accuracy CMMs a rapid measurement, avoiding thermal soaking times.
- If possible these length standards should be calibrated in a bi-directional way. Fig. 1 shows what this means and Fig. 2 how to realize such measurements on line scales and dot scales (center and edge oriented).
- Many such Video CMMs serve for more than mere 2D measurements, thus the length standards must be suited for inclined measurement in space- diagonal lines and back light illumination. Proper inclination devices must exist. Space diagonals require back light illumination as the optical axis of the CMM is inclined with respect to the artefact´s surface and through the lens (TTL) illumination is not viable.
- Artefacts must not move even on moving cross tables.
- The problem of Z-axis verification had to be solved; the use of gauge blocks is a difficult task (improvisation) and contains big uncertainty contributions due to weight changes and manipulation. Diagonal steps are not testing only the Z-axis. Pyramid-like artefacts are limited in height to the stand-off distance of the lens which is normally less than the machine travel in Z. A “Z-artefact” must be suited for auto focus measurement.
- A problem is seen in the definition of bi-directional measurements with chromium on glass lines and circles as now stated in the standard: such idealized features are almost never used in practice; this idealizes as well the performance of the CMMs in the tests or even leads the manufacturers to set parameters which in practice with “real parts” don´t yield the best results. Experiments have been conducted by the author on ceramic spheres and cylinder discs in different illumination modes; the experiments are promising. This is as well important because calibration facilities for line width are rare but state of the art for diameters measured tactilely.

In the following photographs such newly developed artefacts are displayed and explained. Note that <u>no</u> patents were filed for these artefacts from the author.

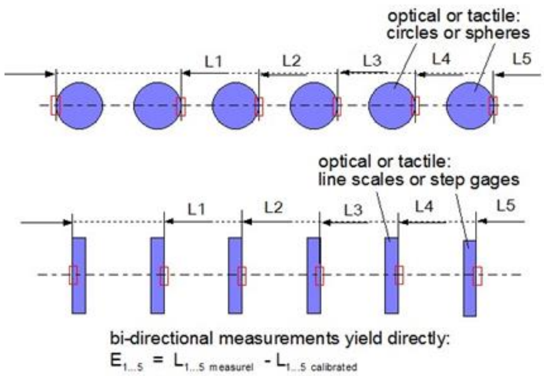

Fig. 1: Meaning of bi-directional length measurements

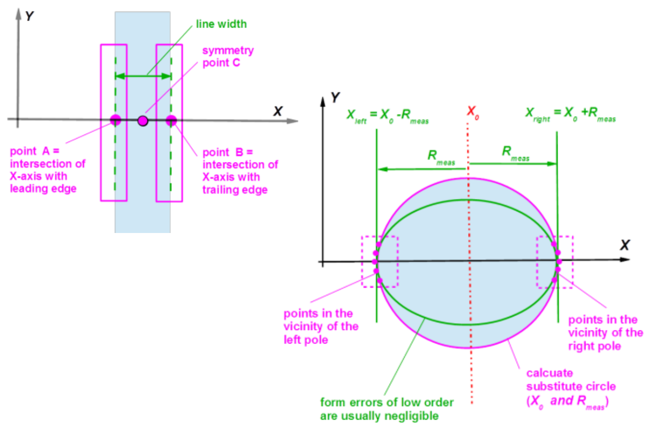

Fig. 2: Measuring lines and circles (centers and edges); the “trick” with dots is to measure around the poles and to add/subtract the measured radius to/from the center position

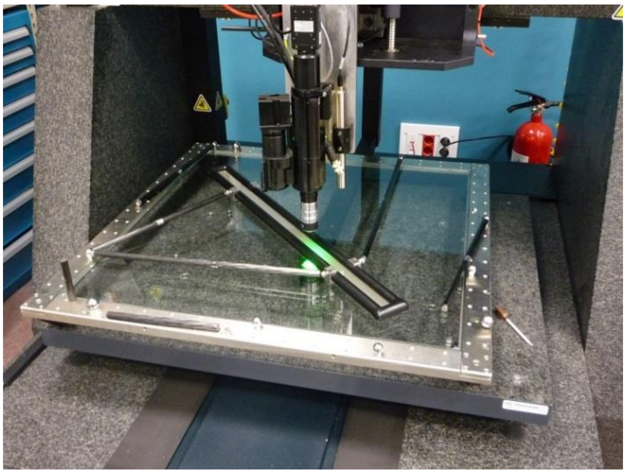

Fig. 3: Line scale of near zero thermal expansion on video CMM in XY-diagonal measurement line; case: “highly dynamic” table; stability is assured by magnetic rod fixtures in statically constrained arrangement

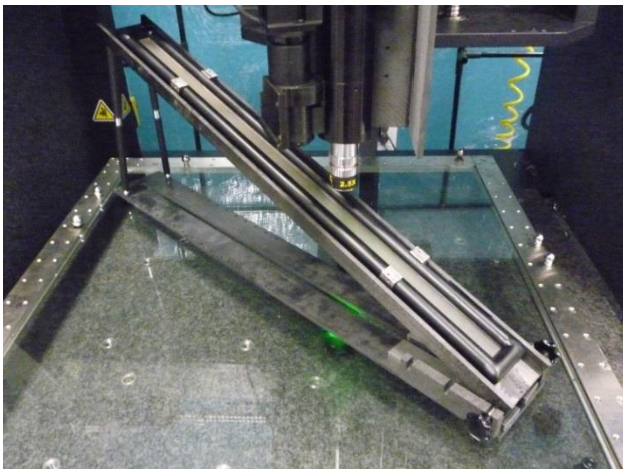

Fig. 4: Artefact on video CMM in space-diagonal placement; inclination device, holder full carbon fiber composite for thermal stability during measurement; support with “window” allows for backlight illumination; stability of inclinator achieved by using high modulus fibers, Continuous inclination angle variation due to magnetic telescopic rods of carbon fiber (left) and pivot axis (right)

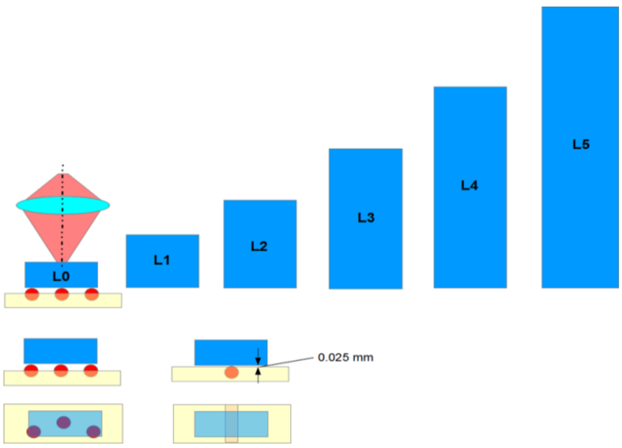

Fig. 5: Set up with gauge blocks, used in the past for verification of the Z-axis (optical axis); different weights of gauge blocks may cause elastic deformations in the supports

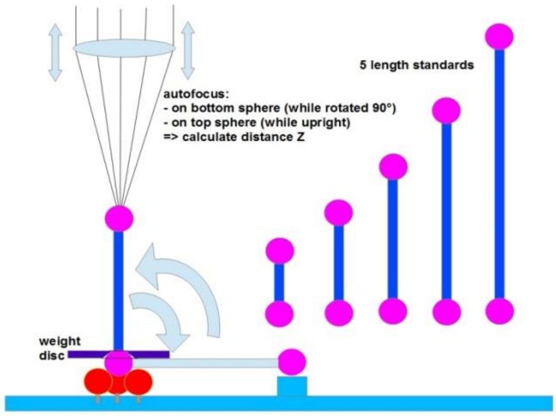

Fig. 6: Method for verification of the Z-axis; center on pole reflex, focus, 3D distance; black pigments deposited in the pores of the ceramic balls improves autofocussing

Fig. 7: Probing on a vertically placed miniature ball bar (right) according to the concept explained in Fig. 6

3. PERFORMANCE VERIFICATION OF CMMS WITH OPTICAL DISTANCE SENSORS AND STAND ALONE OPTICAL 3D MEASURING SYSTEMS

3.1 International and National Standards

Since the publication of the respective international standard the **ISO 10360-8 (2011)** verification of CMMs with such systems is covered. However, the verification of the stand alone scanners (mainly laser scanners and fringe projection systems) is normally done according to VDI/VDE 2634-2 (2012) [5]. If multiple views of the measurement system are involved, VDI/VDE 2634-3 (2008) [6] applies. The basic rules of ISO 10360-8 (CMMs with scan heads):

- In ISO 10360-8 rules are similar to those in the verification of tactile and video CMMs: 7 lines of verification with each 5 lengths, 3 times measured.
- Typically ball beams with 6 spheres are used. The covered length must be 66% of the length of the respective measurement line at least.
- Bidirectional measurement comes in via the probing test as the test sphere is calibrated and measured for diameter too. The sphere shall cover at least 66% of the sensor´s measurement area. Diameter and length errors may thus be added to get the bidirectional length measuring error.
- Additionally flats of typically twice the length of the sensor area are measured.

The basic rules of VDI 2634-2 are:

- Ball dumbbells serve as length and form test artefacts.
- They are measured in 7 lines in the measuring volume.
- The center distance of the balls shall be at least 0.3 times the smallest side length of the measurement volume.
- The diameter of the balls shall be between 0.1 and 0.2 times the smallest dimension of the measurement volume.
- As well: measure flats of a length of at least 0.5 times the smallest side length of the measurement volume.

Artefact materials (surfaces) are very critical for the measurability and undesired uncertainty contributions. A problem is the volume scattering effect of alumina ceramics which shifts the appreciated points, thus changes diameters and positions. Now a special phase mixture of different metal oxides is successfully used. A problem is the still high price for large balls and flats of this material.

Therefore the author has developed a technique applying white paint and lapping the surface mat to geometrical “perfection”. With this technique even large balls and flats as demanded by the VDI standard are possible.

VDI/VDE 2634-3 refers to multi-view measurement where often photogrammetry is involved to reference different views. Rules are similar to VDI/VDE 2634-2 only that the reference ball bars shall be at least 66% of the measuring volume extension and that not such big balls are required: recommendation for the ball diameter 0.02 times to 0.2 times the measuring volume extension.

3.2 Reference Artefacts

A lack of suited reasonably priced flats in the past has led to that the suppliers do simply not perform the tests involving such flats but only those tests with dumbbells. In the following artefacts meeting requirements of mentioned standards are presented. Balls with diameters above 50 mm (up to 160 mm) are made of carbon fiber composite and covered with highly resistive white paint is then precision lapped. As well flats can be made according to this method.

For dental scanners, master parts with similar features as the to be measured features have been standardized: DIN EN ISO 12836 [7]. Fig. 10 shows one of the standardized task specific artefacts.

Fig. 9: Linear array ball beam with special low-volume scattering ceramics on fringe projection system

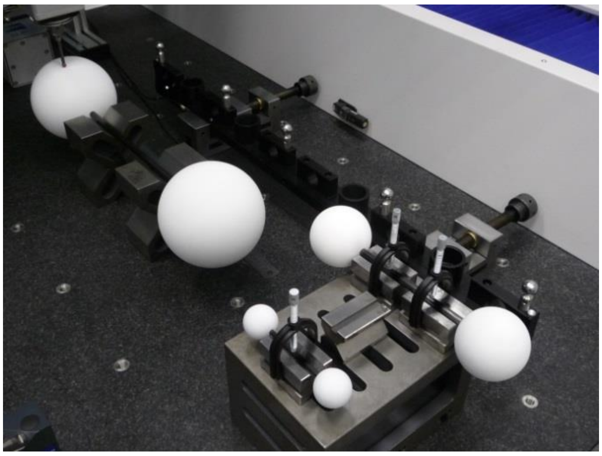

Fig. 8: Different dumbbell sizes, here dumbbells during tactile calibration; all balls with surfaces of fine-lapped paint

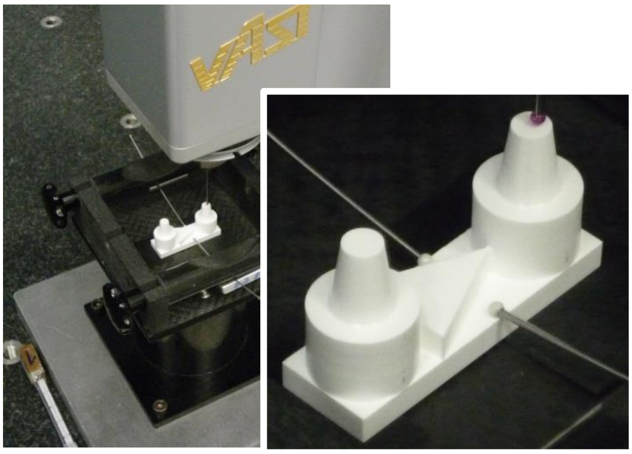

Fig. 10: Artifact for dental scanners during calibration (courtesy: www.ISM3d.es)

4. PERFORMANCE VERIFICATION OF PHOTOGRAMMETRIC MEASURING SYSTEMS

For photogrammetry, international standards are still under development. More precise reference artefacts than the scale bars used in most measurement setups are suggested for system verification. Many artefacts today used have retro-reflecting targets with relatively coarse perimeters of the targets (usually reflecting circles glued on the artifact). One improved target developed by the author (fig. 11) is a black (mat) cylinder with a concentric retrocession in one face which is filled with white paint and rectified so that white and black areas are coplanar. Other similar solutions exist from different manufacturers. The targets are normally placed in the symmetry line of the artefact (no influences from minor bending of the artefact).

An unsuccessful attempt by the author to create sharp and well defined targets is to use black balls in front of retro-reflecting foil (fig. 12). No improvement compared to retro-reflecting dots was achieved: the periphery remains coarse due to the structure of the reflecting foil. One advantage remains: a tactile calibration is possible.

A solution (not yet studied in detail by the author) might be an artefact with glass balls with a fine mat surface. Such balls are as well a kind of retro-reflecting targets (though the reflex is less intense than that of commercial reflex foils). Fig. 12 shows such a ball. The perimeter of the perceived circle is homogenously illuminated and sharp [8].

In fig 12 another possible solution, an internally illuminated ceramic ball, is shown. Here too the perimeter is sharp and homogenously illuminated.

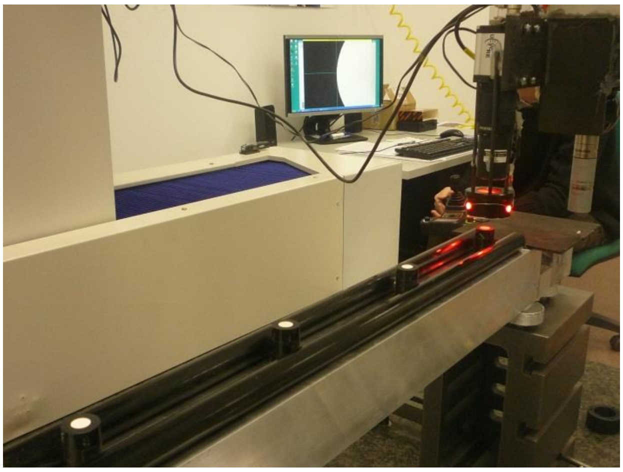

Fig. 11: Artifact for photogrammetry by the author, targets with plane surfaces and sharp circles during calibration (calibration set up: courtesy www.ism3d.es)

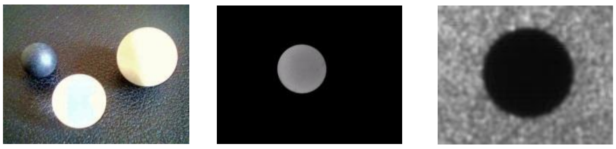

Fig. 12: Mat glass ball (left picture center) as a target for photogrammetry artefacts in comparison with ceramic ball (3rd ball from left), internally illuminated alumina ball (center picture), and black ball in front of reflex foil (right)

5. PERFORMANCE VERIFICATION OF TOMOGRAPHICAL 3D MEASURING SYSTEMS

For tomography, standards are still under development. We may assume these future standards to be harmonized with the ISO 10360-series (e.g. number of positions and lengths). Artefacts developed by the author are shown in the following. According to system manufacturers materials with low atomic weights shall be used (carbon fiber, alumina ceramics, ruby).

6. CONCLUSIONS

Today, suited artefacts to serve the need of most standards on optical inspection systems for geometrical features in industry are available. Some standards for industrial optical measuring systems still need to be terminated on international level. It is mainly now for the users to demand standardized performance verifications from the manufacturers.

Fig. 11: Dumbbells for tomography on stand

Fig. 12: Miniature tetrahedrons for tomography on stand; the springs of carbon fiber are so-designed that the balls are pressed together with equal forces, no glue needed, ruby

7. REFERENCES

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