Industrial Metrology (and 3D Metrology) vs. Geodetic Metrology (and Engineering Geodesy). Common ground and topics

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Abstract: The very accurate measuring of three-dimensional models of complex surfaces and objects in general (and their creation, as well), are subjects of the three-dimensional Metrology (3D-Metrology). In order 3D-Metrology to connect effectively the physical world with the virtual world (and vice versa), there is a need of measurements, methodologies of measurements and calculations. In this area, the contribution of the science of Geodesy, a science of spatial measurements, is of paramount importance. In this paper, a review and analysis of both, methods (or principles) and measuring instruments are carried out. These methods and instruments, although they belong to Geodesy (specifically in a branch of it, also known as: Geodetic Metrology, Technical Geodesy or Industrial Geodesy), they also form fundamental milestones of 3D-Metrology.

1. Introduction

The science of Geodesy deals with the theoretical and practical study of instruments and methods for performing measurements, calculations and visualisation, that are useful for determining the shape and the size of the Earth's surface (parts of it or all) (Doukas 2005). Because it is a science with many interdisciplinary ramifications and covers a really wide area, it is arguably structured in several sub-sectors/branches (e.g. Physical Geodesy, Mathematical Geodesy, Electronic Geodesy, Satellite Geodesy etc.). So, among these branches, there is the branch of *Engineering Geodesy - Technical Geodesy* (which in English can be satisfied under the names: *Industrial Geodesy, Geodesy Engineering - Industrial Geodesy, Engineering Geodesy, Engineering Surveying, Geodetic Engineering*, and in German as: *Ingenieurgeodäsie*). In simple words, this is the geodetic sector that is related with the monitoring of various physical and technical projects, along with the measurements taken (concerning the phases of: design, setting out and construction).

While Geodesy (i.e. the "root"-science, the superset-science) generally deals with very large surfaces/volumes (for example, with the Earth as a whole, with a country or part of a country, etc.), Engineering Geodesy (as a subset) deals with much smaller "regions" (e.g. inside a mine, a tunnel, etc.), and the measurements have to do with reasonably smaller objects, such as e.g. the magnets and other components of a particle accelerator. Even more, Engineering Geodesy also includes a wider range of techniques and methods that are between other important sectors of Geodesy such as: Geomatics (Geomatics) (i.e. the science of collecting, storing, processing and disseminating geographic information) and Photogrammetry, as well. In any case, nowadays these geodetic branches have fuzzy boundaries between them. From this aspect, Engineering Geodesy includes new methods developed by using electronic instruments. Others of its methods are based on mechanical or optical measuring instruments, or generally, are based on various combinations of all these instrument-kinds.

The term *"Three Dimensional"* or *"3D-Metrology"* means a 'hybrid' of science and art (!), which, creates (with exceptionally high accuracy) three-dimensional objects and highly complex surfaces, based on the measurement of three-dimensional data (in x, y, z coordinates). This is a "bridge" that leads from the real object to the theoretical model and, vice versa, from the theoretical model to the new (and precisely constructed) object.

Industrial Metrology (which in several countries coincides with *"Scientific Metrology"*) aims to the well function in the measuring instruments used in industry but also in generating products and inspection procedures for these (Doukas 2005). Industrial Metrology denotes measurements of spatial dimensions. Such measurements are also carried out by geodesists (and surveyors, as well.....). In the field of Industrial Metrology, the accuracy-specifications of measurements are generally ranging in the interval of micron (0.001mm) to mm.

By following a simplified approach, the intersection of these sets: Engineering Geodesy, 3D-Metrology and Industrial Metrology, results into the set: ***"Geodetic Metrology",*** i.e. on the one hand the use of geodetic techniques and instruments for measuring items, but on the other hand, where precision/accuracy matters it will obey the requirements of the Industrial Metrology (and the 3D-Metrology, as well). So, being dependent on the dimensions of the measured object, the achieved accuracies are better than 1mm up to a few cm. When now it comes to machines and other large structures in general (such as a tanker ship, an aircraft, etc.), then the term of Geodetic Metrology can be met as *"**L**arge-**S**cale **M**etrology" (**LSM**)* or alternatively, as *"**L**arge-**V**olume **M**etrology (**LVM**)"*. At the one end of Geodetic Metrology there are the laboratory measurements and at the other end there are the geodetic measurements, where both these ends are not clearly defined (Estler et al. 2002). The overall picture of modern industry shows that geodetic methods are used internationally and widely. When the case is the measurement of quality control, the geodetic methods are undoubtedly extremely efficient and fast. When manufactured products (and parts thereof) are three-dimensional objects, then obviously the measurements must be three-dimensional, as well. Apart from pure industrial applications, as will be explained below, the applications of Geodetic Metrology are diverse. Metaphorically, geodetic methods (and instruments thereof) could be considered as a kind of coordinate measuring machines, and one fundamental to their major strength is their capability to provide ***absolute coordinates*** (Doukas 1988), (Kavvadas 2005). From here on in this paper, the generalized term: ***"Geodetic Metrology (GM)"*** will be used.

The plethora of different applications encountered in the field of GM, is reasonable and it usually makes each case to be treated as a unique one. Furthermore, compared with the corresponding objects with small-size volume, the large-size volume of objects typically requires different treatment (in terms of methods, instruments and measuring scenarios). In any case, the formal requirements of GM include:

- Measurement automation (to maximize/optimize productivity).
- Ability to assess (and measure) inaccessible points in space.
- Receiving of measurement information about the geometry, shape, position, etc.
- High accuracy and speed modes concerning data (i.e. measurement, receiving, downloading).

2. Categories of metrological instruments (systems)

The categorization of metrological instruments (and systems) is extremely difficult because of the multiple functions (multi-modes) encountered by most of them. Based on several aspects encountered in the literature (Muelaner and Maropoulos 2008, Estler et al. 2002, Kavvadas 2005, Kahmen and Reiterer 2004, Khan 2009, Leica 2009, Savio et al. 2007, Vasilash 2009, Doukas 2005, Stempfhuber 2006), another attempt here results into two types of categorization, as follows:

2.1 Categorization based on specific parameters and characteristics

This categorization has to do with specific parameters and characteristics of the metrological instruments:

1. *The scale* (in the sense of the magnitude of the volume of the object): It is reasonable that in general, the metrology accuracy is inversely proportional to the scale on which the measurements are carried out. In common tasks, depending on the instrument, manufacturer, model, composition and measurement scenario, very high accuracy requirements (e.g. in aeronautics, in the vehicle industry, etc.) are possible to be achieved.
2. *The possibility of measurements in parts or in total:* Other instruments measure multiple points in succession in the series and other instruments measure many points massively and simultaneously.
3. *Accuracy, precision, repeatability* (concerning instruments/measurements).
4. *Frequency and number of measurements:* The number and frequency of meas-

urements is difficult to be determined, as most metrological institutions can demonstrate superior performance (many and rapid measurements in short periods) in this area. On the other hand however, a single measurement may be deficient in accuracy. Typically, in order to improve the accuracy, the averages of several measurements are used. Alas the maximum accuracy is never achieved simultaneously with the maximum frequency (number) of measurements.

5. *Richness of provided information:* Each instrument (and system) provides different information, especially when deals with the three dimensions. More specifically:
   5.1. *One-dimension systems (1D):* Here "traditional" metrological instruments (such as the micrometer, the thickness gauge etc.) are met, as much more modern ones such as the Laser-interferometer.
   5.2. *Two-dimension systems (2D):* Some of these instruments are capable to detect two-dimensional objects (e.g., to locate a sensor, or to place a sensor on a surface or perpendicular to it). Other of these instruments are capable of measuring other features (p.e. holes, etc.).
   5.3. *Systems of three-dimensional (3D) measurement:* For specific positions in space.
   5.4. *Systems of three-dimensional (3D) surface-characterization:* Systems that, since they ensure the appropriate visibility, are capable of "locating-defining" the full shape of an object and, even more, to digitize this object.
   5.5. *Systems with 6* ***D.O.F. (D****egrees* ***O****f* ***F****reedom):* They can measure both, the coordinates and the rotation of an object (they are very useful in providing feedback in automation).
6. *The operation at a specific location or in space-distribution:* For example, a Laser tracker is an instrument that can only carry out measurements, when it is located in a certain position. On the other hand, if the task is to measure the coordinates of specific points, then a number of theodolites could be distributed in space. Even more, there may be specific instruments distributed in space to form a measurement-network, which aims to: (a). Improve the attainable precision/accuracy. (b). Expand an existing network of measurements beyond the range of vision of a single instrument. (c). Improve the information provided by 1D-instruments, in order for the outcome to be (x, y, z) coordinates.
7. *Related to information transferring:* Either from the measured point to the reference system (datum) of the instrument used, or from one measurement to the next one.
8. *Measurement-type:* If measurements require physical contact or could be carried out remotely.
9. *Total software support* (instruments, communication, resolution, analysis, etc.).
10. *The operating environment.*

2.2 Categorization, either by automation or by GM

In geodetic instruments, there is diversity in their automation, such as:

- *Simple electronic systems:* Electronic theodolites or total stations that "require" both, the observer' s contribution together with a personal computer (PC) (the PC directly controls the measuring process, saves the data and performs calculations).
- *Electronic total stations or robotic theodolites:* They are motorised (with dedicated servo-mechanisms), which can be "taught" a series of movement-measurements, which later on they reproduce without any assistance from the observer. Others can receive instructions on the measurements under process from a connected PC "running" proper dedicated software.
- "Smart" (robotic) systems, in which various sensors are combined. For example, they may have a CCD camera (where **CCD** means: **C**harge-**C**oupled **D**evice) for automatic target detection (**A**utomatic **T**arget **R**ecognition - **ATR**). Such systems are capable of performing measurements to: detect vibrations, monitor (via ATR) target moving, calculate (in real time), give the results, even modify 'themselves' (i.e. the originally given "scenario" for measurements).

The term *'robotic measuring system'* (most commonly, used in many different applications), means a system which has the following properties:

➲ It moves automatically around its main axes (based on appropriate commands) and can perform repetitive "scenarios" of measurements.

➲ It memorizes and automatically performs the installed "scenarios" of movements and measurements.

➲ It can "learn". The acquired knowledge is kept in its memory and then it is used. Depending on the case, such a system adjusts (adapts, modifies) its operational schedule accordingly.

The term 'robotic' obviously means in many cases nowadays that the participation of ***A****rtificial* ***I****ntelligence (AI)* is strongly present in systems and applications of GM (IAG 2013).

From the scope of GM, the related geodetic instruments and systems could have the following categorization:

A. Instruments measuring, angles, distances and height differences:

For angles: Theodolites (conventional or most commonly today, digital electro-mechanical).

For distances: **E**lectromagnetic **D**istance **M**easuring **I**nstruments (**EDMI**), using infrared or Laser (monochromatic, polychromatic). The Laser interferometers are met in the highest accuracy class.

For height differences: Levels (conventional or most commonly today, digital electro-mechanical). The Laser levels combined with special bar-code staffs there are in the highest accuracy class.

Fig. 1: *Surveying (geodetic) metrological-instruments – An indicative sample*

For multi-measurements: The total stations, which combine the measurement both of angles and distances.

B. *Systems for the measurement and determination of points in the 3D-space:* This sector is the most populated (concerning instruments, methods, high technology, etc.). All major companies of geodetic (surveying) instruments (e.g. Leica, Nikon, Sokkia, Topcon, Trimble) offer a wide variety of models and prices. Much detailed information can be found in their web-sites. In this paper, the limited space leaves room only for typical characteristics of each category.

B1. *Systems based on the method of 3D-resection:* With this method, the minimum requirement is to use two digital theodolites (either robotic or not), which are connected to a personal computer. Both instruments are placed on special tripods and to determine the coordinates (x, y, z) of a point in space, this point is sighted simultaneously from both theodolites and the two vertical and two horizontal angles are measured thereto. For measuring a surface (e.g. a monumental facade), two theodolites are enough. If the case relates to the measurement and accurate mapping of a solid (e.g. a building, a bridge), then an accurate triangulation network needed with many angle measurements by more than two theodolites. Today, such a system can reach all eight (8) cooperating theodolites, and the least-squares adjustment of observations finally gives the coordinates of all involved points.

- B1.1. *With non-motorised theodolites:* Such a system may consist of two (2) to eight (8) theodolites with special software. To facilitate targeting, one theodolite can be equipped with an additional Laser-beam transmitter, the radius of which (i.e. of the trace dot) helps to identify and sight targets from other theodolites. The accuracy of angle measurement varies from ± 0.005gon to ± 0.00015gon, while (under normal conditions) the mean measurement-rate is approximately 50 points per hour.
- B1.2. *With motorised robotic theodolites equipped with a CCD camera:* It is about theodolite-sets (2 to 8 instruments), and at least one PC. Most commonly, there is a primary PC (with installed software for calculations and analysis, loaded also with the measurement files) and at least one auxiliary PC (networked with the primary PC), for testing measuring scenarios of the connected to it theodolites. The accuracy of angle measurements varies between ± 0.00010gon ÷ ± 0.00015gon. For better targeting, theodolite-models equipped with Laser-beam transmitter can be used, and/or theodolite-models equipped with a CCD camera for the automatic recognition of targets. Generally, when the method of 3D-intersection is used (where, either the involved theodolites are motorised or not), the final achievable accuracy of coordinates determination (x, y, z) is of the order of ± 0.05mm ÷ ± 0.1mm.

B2. *Based on the method of polar coordinates:* By this method, a high precision theodolite is used combined with an (also of high precision) EDMI. The coordinates of the control points, as they obtained from measurements of angles and lengths, are polar (not rectangular). As "target" on the points of interest, special reflective bodies (reflectors or tapes) are utilized. The use of a digital motorised theodolite or a high precision total station (which can be conventional or servo-motorised), really improves this method. Today the normal rule is the use of an electronic theodolite in connection with a portable PC (where appropriate software is loaded). Regarding EDMIs, it is (alternatively) possible to use special distance measuring instruments, without requiring reflectors (a fact which allows unobstructed measurement and at points located on inaccessible surfaces). Generally, the method of polar coordinates (either with conventional or motorised theodolites) allows for angles accuracy ± 0.15gon ÷ ± 0.5gon, for lengths [(± 1.0mm ÷ ± 3.0mm) ÷ (± 1.0ppm ÷ ± 3.0ppm)]. When distances between target and instruments are between 100m ÷ 1,000m, the final achievable accuracy of (x, y, z) coordinates determination can reach ± 1.0mm ÷ ± 1.5mm. Generally, comparing systems using the 3D-intersection method with systems using the method of polar coordinates, in many cases they are complementary to each other.

Also, for short distances, the achievable accuracies are more or less at the same level, but the general rule is: For short distances and extremely increased accuracy requirements, the proper choise is the method of 3D-intersection. For long distances and not extremely increased accuracy requirements, the proper choise is the method of polar coordinates.

C. *Instruments of Photogrammetry:* In simple words, the term 'Photogrammetry' means, "measuring by using photographs (taken from the air or on the ground)". Essentially, three-dimensional objects are measured by comparing two or more two-dimensional images, taken from different positions. Common points identified on images allow determining the line of sight (from each point to the location of each camera). So, by knowing the location of each camera, the least-square adjustment of the established triangulation results into the determination of the points-positions. The "targeting" of points (accessible or not) could be achieved by using either, specific targets or auxiliary Laser-instruments (which produce Laser-dots as targets).

D. *Based on the Videogrammetry:* It is a measurement technology in which the coordinates (x, y, z) of points on an object are determined by using video images, taken by different video-cameras (and angles, respectively). Thus, the solids are "digitized" rapidly (or are being monitored in real time, concerning their deformations). Most commonly, special CCD video-cameras are utilized. The accuracy of the point determination can reach ± 0.1mm. The basic drawbacks of the method are, the small dimensions of the captured frames and the high cost.

E. *Instruments (systems) based on Laser technology* (Estler et al. 2002, Jacobs 2009, Khan 2009, Lemmens 2009, Monserrat et al. 2008, Savio et. al 2007, Vasilash 2009):

E1. *Laser tracker:* The operating principle of the Laser tracker is much like that of the total station (since it measures distances with electromagnetic Laser-radiation (essentially an Interferometer Laser), and it uses special mechanisms for measuring horizontal and vertical angles). For the measurement of the distances, a **S**pherically **M**ounted **R**etroreflector (**SMR**) is required. The achieved collection rate of an average of 3,000 points/sec is attainable. Combining these measurements, it is possible to determine the coordinates (x, y, z) of a point, with only one position of the Laser tracker (when a theodolite needs at least two positions, for the same one point). The obtained accuracy for angles is approximately ± 0.00015gon, while for distances is ± 2ppm. In a simplified view, the Laser tracker is a portable coordinate measuring machine (**CMM - C**oordinate **M**easuring **M**achine), but offering many more features and flexibility.

E2. *Laser scanner (also known as: **LIDAR-L**ight **D**etection **A**nd **R**anging):* The principle of operation is much like that of a geodetic total station. Depending on the model and the manufacturer, such instruments can operate with collection rate >100,000 3-D-coordinates/sec. With a Laser scanner, the object under measurement is scanned with a Laser beam. The instrument detects the scattered light of the beam. The resulting digital images are automatically saved on a PC and the (x, y, z) coordinates are obtained through dedicated software (which furthermore implies, 3D-pictures and 3D-drawings in the results), with an average accuracy around ± 5mm.

- *Similarities between Laser trackers and Laser scanners:* They both emit Laser radiation by a specifically shaped head (which is based on specific global basis such as a compass or a gyroscope). They offer high accuracy and are effective in a large range of distances.
- *Differences between Laser trackers and Laser scanners:* Due to the necessary relationship between the instrument and the SMR-reflector when using Laser trackers, they require contact with the object as the specific SMR reflector must be placed onto the measured object points. Furthermore, additional work is needed for moving and positioning of the reflectors. On the contrary, Laser scanners are totally "non-contact with the subject" and they operate automatically. No targets are needed, since it is just enough if the surface to be scanned has >10% reflectivity.

E3. *Other relevant instruments, based on Laser technology:*

E3.1. *The portable CMM Arm:* An instrument for the inspection of objects, assembly and fittings, the so-called 'reverse engineering', etc., with accuracies of the order of ± 0.25mm. For over twenty (20) years, it is equipped with a special Laser-scanner.

E3.2. *The **L**aser **D**oppler **V**ibrometer (**LDV**):* A scientific instrument that is used to make non-contact vibration measurements of surfaces. These instruments are accurate enough to be used as a calibration reference source.

F. *Indoor-GPS:* Based on the operating principle of GPS, this method uses special transmitters fitted around the under measurement (or inspection) object, and communicate with special sensors (where these sensors have the role of "satellites" of the GPS system). This one-way (through 'sensor-to-receiver' signals) communication, gives the sensor location. The accuracy achieved from modern sophisticated systems of this kind, approaches ± 0.1mm.

Starting primarily with Laser and GPS applications, all the above important modern technologies (instruments, methods, etc.) 'circulate' between different branches of Geodesy (together with Geomatics and Metrology). It was just a matter of time to create a new trend in geodetic things, the so-called «**H**igh-**D**efinition **S**urveying» (**HDS**) (Khan 2009).

3. Standards and Specifications

Regarding to the geodetic instruments, there is *'ISO Technical Committee TC172 / SC6'*, responsible for the production of newer standards *ISO 17123*. Many of the "basic principles" governing the area of Geodesy have not been accepted everywhere as standards. Generally, for more kinds of field geodetic instruments, the prevailing standards are usually the respective local-national ones. Related to the above, the following are identified (Doukas 2005, Muelaner and Maropoulos, 2008):

- *Standards ISO 10360-2:2002:* The tests and standards related to ISO 10360 (BSI 2002) are a clearly established framework regarding the coordinate measuring machines (CMMs). In this paper, they just mentioned, as not germane to the geodetic instruments of GM.
- *Standards ASME B89.4.19:* They are related to the "Measuring Systems of spherical coordinates", which of course are associated with Laser trackers and Laser scanners. These standards define two types of tests: (i). Tests of systems (subsystem of angles measurement, subsystem of distance measurement) and (ii). Tests of the range.
- *Standards ISO 17123:* The standards ISO 17123 (parts: 1 to 4) have their roots in the German standard DIN 18723 (Part 1-8). This standard deals with theodolite-type instruments. Part 1 (ISO 2002) covers the whole theory on field-testing of geodetic (surveying) instrumentation, and Part 3 (ISO 2001) deals specifically with the theodolite. The overall picture shows that the existing ISO 17123 standards focus on geodetic instrumental tests related only to the field measurements, and not related to existing standard metrological procedures should be followed in intra-laboratory calibrations of such instruments. The tests of this standard actually measure the repeatability of the instruments and

not their accuracy. Such problems pushed the International *Federation of Surveyors (**F**édération **I**nternationale des **G**éométrés - **FIG**)* to do more on the issue of standards and standardization, in cooperation with the ISO organization. Among others, their actions resulted into the creation of the working group 5.1 (FIG Working Group 5.1), which reports back to the Commission 5 (Commision 5 - dealing with the positioning and measurements) (FIG 2014).

4. Techniques and applications

By using the above-mentioned instruments (and systems) in various combinations, it is proven that they significantly improve the achieved accuracies, in combination with a corresponding reduction in costs (due to a corresponding reduction of inaccuracies and generally, of problematic measurements). At the same time (Jacobs 2009), there is an improvement of the security on the measuring site, concerning personnel (e.g. because of the non-contact when measuring 'dangerous' (or hard to reach, or inaccessible) objects or spaces).

The basic techniques of Metrology (and of course GM) have to do with:

- Data localization: Point identification in space (without or with geometrical parameters)
- Either, zone-fitting or minimum zone-fitting, on data.
- Parameter optimization (by using measurement data).

These techniques are fundamentally contribute in key engagement areas of Metrology, such as:

- ➲ *Custom manufacturing:* Compared with the mass production of standard products, the production (manufacturing) of specialized products (rapid prototyping) is now easy, fast, economical, even for large production numbers.
- ➲ *Digital archiving:* This is a great benefit, especially when 3D-representations needed but there are no existing CAD files. With the GM techniques, the physical characteristics of existing physical objects and other formations and structures are recorded (registered).
- ➲ *Industrial design:* Great ease of transition, from "natural" or "designed - carved by hand" forms, to the production of finished products.
- ➲ *Quality control:* Based on given precision specifications, quality and tolerances, the comparison between accurate digital models with corresponding CAD drawings is very easy and comfortable.
- ➲ *Reverse Engineering:* The creation of accurate digital models of existing objects, redesign and improvement of existing products.
- ➲ *Visualization:* Digital "expressions" of complex 3D-models, opportunities for cooperation and distribution of "3D-descriptions of physical objects" between

technicians and other staff. It is a great tool, either for the improvement of decision-making or strategies-selection.

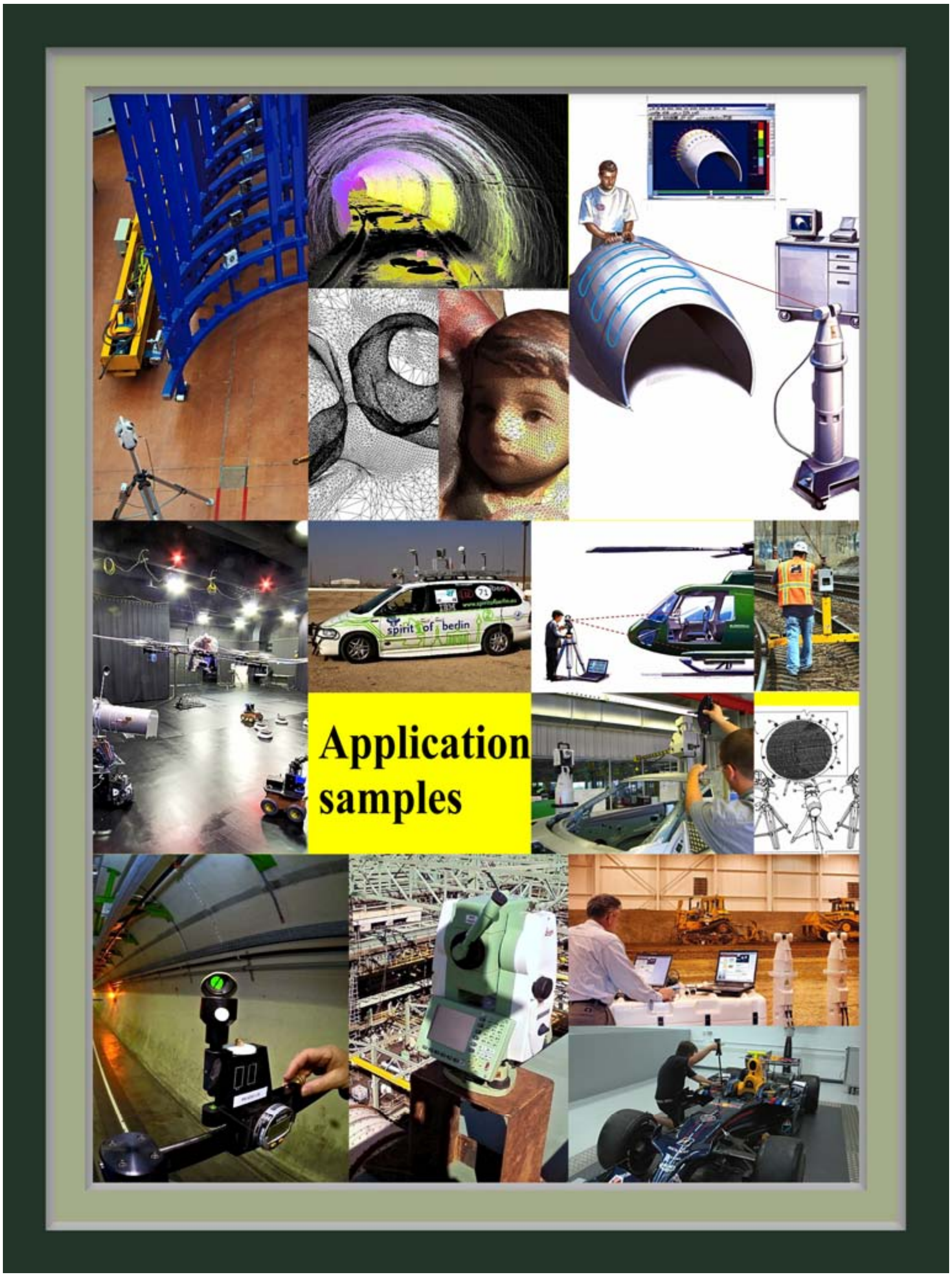

Fig. 2: *Geodetic Metrology (GM) applications – An indicative sample*

The GM-applications are many and varied, while the related literature is truly immense. Some representative applications (mainly in large groups) are indicatively given below. Based on a selected bibliography, such applications can be divided into two general categories:

I. Geodetic applications (e.g. Doukas 1988, Doukas et al. 2004, El-Hakim et al. 2008, ETH 2014, FIG 2014, Kavvadas 2004, Moullou et al. 2008, Psimoulis and Stiros 2007, Stiros 2009, Wang et al. 2009):

- ➲ Measurements and monitoring, relating to the deformation of physical structures (e.g. soil, ground slopes, landslides, seismic faults, etc.).
- ➲ Measurements and monitoring, concerning the deformation of man-made structures (e.g. dams, mines, tunnels, bridges, buildings, chimneys, industrial floors, aqueducts, etc.).
- ➲ Surveys of buildings and other construction-works.
- ➲ Special surveys of archaeological monuments and sites.
- ➲ Special geodetic works for the design and construction of underground particle accelerators, a particular GM-field with extremely high requirements of accuracy (Bocean 1993, CERN-SU Group 2009, Glaus and Ingensand 2002, Greenwood and Wojcik 2006, Leica 2009, Mayoud 2004, Quesnel 1997).

II Industrial applications (e.g. Estler et al. 2002, IAG 2013, Jacobs 2009, Leica 2009, McClenathen et al. 2008, Monserrat et al. 2008, Muelaner and Maropoulos 2008, Muske et al. 1999, Savio et al. 2007, Wang et al. 2009):

- ➲ Aerospace, shipbuilding, automotive (and general vehicle industry): Checking cross sections, dimensions, shape and form fitting, slip, symmetries, position-detection and control of connections of individual parts, fitting of engines, etc. Today, the experimental modeling (simulation) it is easily possible concerning e.g.: controlling of cargo, flight-testing, the "application" of virtual components before they are built, etc.
- ➲ Space industry: Tests and controls of form, motion, strength, deformation sections, geometrical characteristics of antennas, mirrors, telescopes, radio telescopes, satellites, etc.
- ➲ General industry: Tests of flatness, cylindricity, sphericity, etc., installation - assembling - placing of large machines, point-to-point motion determinations, specific checks in "special industries" (e.g. nuclear power plants, blast furnaces, etc.), mounting and installation of wind turbines, offshore constructions etc.

5. Epilogue

Industry, technology, and various developments in: science, instrumentation, measurement methodologies and techniques, are factors asking for faster, more flexible, safer and more precise measurement solutions. All these demands live in conjunction with:

(i) The strong tendency of requirements for better and more attractive products.
(ii) The reduction of production costs.

Constantly in industry, the surfaces and the components become more complex, the materials change, the bar of expectations concerning tolerances is rising and so, even the slightest deviation from the accepted tolerances leads to malfunctions, failures, safety problems, increase of expenses and/or of energy consumption. Traditional CMM-machines are no longer sufficient, large and heavy industries (of variable kinds) exhibit increased demand for accurate in-situ measurements (e.g. concerning: objects, parts, whole complex constructions, etc.), in all phases of production.

Thus, it is easy to understand the increasing penetration-speed (an the impact, as well) of GM measuring-systems (e.g. indoor-GPS, Laser scanners, Laser trackers, 3D-resection systems, etc.). The issue is even more interesting and complex as it is often necessary to combine (completed) measuring data of many different measuring systems, where it is reasonable that there is a wide variety of output precision/accuracy (depending on the instrument - measuring system). Generally, the trend throughout the industry shows new research and applications that basically are trying to bring ever closer together, the product (from its conception and design, to its construction) with the Industrial Metrology (serious part of which has long been dominated by instruments and methods of Geodetic Metrology).

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