Methods for Industrial Measurement and
Basic Principles of Their Choices

FENG Wenhao

1 Diversity of industrial objects

1.1 Industrial object

The objective of industrial measurement is to deal with problems as design, modeling (including emulation), detection, lofting, quality control (including determination of assembly lines and robot action tracks) and dynamic monitoring related to the shape, size and action status of objects.

There are a diversity of objects for industrial measurement, such as:
- the airplane configuration measurement for designing, copying and reconfiguration,
- surveying, detection and sampling in the space shuttle designing, installation and debugging,
- car configuration measurement, especially the surveying tasks in the designing, copying and reconfiguration process for the car body with a point location precision of ± (0, 1-0, 2) mm,
- ship body configuration measurement concerning the designing, reconfiguration and copying of the ship body,
- mensuration of the cabin volume of the oil ship,
- performance detection and checking of the ship model in the testing pond,
- designing and copying of the canopy configuration,
- dynamic performance testing of the sail configuration,
- configuration mensuration for the propeller vanes of large ships or naval vessels, installation of main facilities of ships,
- indirect mensuration of the total pressure given by the ship body to the dock when berthing [1],
- the inner structure measurement, which is the weak point in surveying and measuring,
- dynamics parameters mensuration of objects in wind tunnel lab and hydrotechnics lab and so forth.

KEY WORDS
industrial measurement; choice; method; principle

ABSTRACT
In this paper, a variety of industrial objects are systematically analyzed. Ten methods for industrial measurement are summarized. For each method, its nature, advantages, disadvantages and adaptability are briefly given. The basic principles to choose the right industrial method are indicated.
1.2 **Object dimension**

The measure for each object in industrial measurement is of much difference, which directly relates to the choices of measurement methods. Maybe there are different viewpoints to distinguish industrial object measure. Here, it is roughly divided into five levels as less than 1 mm, 1-50 mm, 50 mm-1 m, 1-10 m and more than 10 m. This classification has a certain fuzzy relationship with electronic micrometering, optical micrometering, routine industrial measurement, industrial photogrammetry and other means.

1.3 **Precision requirement for object measurement**

Obviously, the precision requirement relates to the measurement means as well as the facilities, technical force and economic investment corresponding with the measurement means. Here, the precision requirement is roughly divided into five levels as nm, μm, sub-sub mm, sub mm and mm. The five levels cover the precision requirement of almost all industrial objects.

1.4 **Surface quality and shape of object**

The surface of many objects lacks texture (including feature point) with a nearly identical tone. Dead angles for observation caused by the mental-like lustrous appearance, glass-like transparency and complicated surface structure have a direct effect on the choice and degree of difficulty of the measurement means.

1.5 **Speed requirement for object measurement**

To provide measurement results within days, hours, minutes, seconds and even at real time (1/30 s-1/25 s), different object needs different measurement speed. The measurement speed has a very close relationship with choice of measurement means.

1.6 **Surroundings**

The surrounding of objects will directly affect the choice of measurement means. The surrounding conditions include distance between the measure-
can be used for the 3D coordinate measurement of some points on the small-scale operation apparatus. Pay attention to the calibration of verticality and division when using this kind of facilities.

2.1.3 Mechanical 3D coordinate measurement facilities

The kernel of this type of facilities is the measurement head that can move along the three coordinate axes and record the 3D coordinates. The measurement range of CHN2015 online coordinate measurement machine is 3 000 mm × 4 000 mm × 5 000 mm with a resolution of ± 0.01 μm. The real precision has a relationship with the measured length L, which is ± (40 + 50L / 1 000) μm. The precision and theory of the facilities is intuitive and simple. They can be linked with computers and the afterwards processing methods are almost normative. However, they are costly and can only be used to measure static objects that are smaller than them. The measurement speed is very limited owing to the fairly high cost. Generally, the special facilities for mechanical 3D coordinate measurement are of a large size, in fact, in scientific institutes or enterprises some (machine tool) facilities with 3D movement and relevant records can be used as 3D coordinate measurement facilities when adding optical micro devices.

2.2 Methods based on special 1D sensors

Many factories and scientific institutes have various kinds of mechanical or electronic sensors, most of which only have the function for 1D measuring. The automaticity of this kind of sensors is high, which is fit for a certain working procedure in a certain working flow or industry, such as the real-time sensor for oil or water surface level.

2.3 Optical micro 3D measurement method

On the basis of the limited focus distance principle of optical microscopes, by adding a certain elevation reading appendix, the optical microscopes may have the function of 3D measurement. These appendixes may be simple micrometer dials or online raster rulers. When measuring a delicate industrial component of 4 mm with a micrometer dial, the elevation precision may reach ± 0.03 mm.

Move the object to be observed on the sample platform with the photographing facility of the optical microscope (such as the common camera or online CCD) to obtain the stereo image after zooming in. Obtain the digital surface model of the microcosmic object by means of the micro photogrammetric processing. The common amplification of micro photogrammetry is of hundreds times. The utmost precision is the wavelength of the visible light. The general object size is of μm level.

2.4 Electronic micro 3D photogrammetry method

The wavelength of high-speed electron beam is only 1/100 000 of the visible light’s wavelength. The resolution may reach 5 × 10⁻⁹ mm. It can be widely used in the fields as mental physics and macromolecule chemistry as well as 3D measurement for minerals, mental surfaces, cells, pollen and even viruses and a single molecule[2]. By revolving the sample platform, stereo images that have been amplified hundreds thousand times or even larger can be photographed. And then the real 3D model of the photographed ultramicro object can be acquired. Because of different imaging principles, the electronic microscope can be classified into many types, such as TEM with an amplification factor of over five hundred thousand and a resolution of no less than 0.3 nm, and SEM with an amplification factor of over two hundred thousand and a resolution of no less than 3.0 nm.

2.5 Method based on Moiré and Newton ring

The Moiré method is specially used for rapid and continuous recording dynamic objects, such as the form change of animal’s body surface, machine tool shaking record and concussion record for horn diaphragm in acoustics design. The creation of projection Morié is freer with a stronger adaptability. However, this method is only fit for the stable and slow objects that the surface undulation is not obvious. And it also requires the high consistency of the surface tone of the objects to be measured. The precision of Morie has a relationship with the raster space interval[3].

The Newton ring is an interference fringe, which is often used to check the surface processing quality
of optical components. When vertically irradiating
the optical component and the flat glass setting it
off with a monochromatic source, Newton ring,
round fringes with the touching point as the center,
will be formed on the air film in the middle. The
center fringes are sparse, while the border fringes
are dense. After measuring the space between of
the round fringes with a microscope, according to
simple relational expressions, the processing preci-
sion of different parts of the component can be cal-
culated. The precision may reach 0.01 μm. Though
the precision of Newton Ring method is high with
simple facilities, it can be only used for the detec-
tion of optical component processing quality with a
small depth.

2.6 Method based on holography

Holography is a technique to simultaneously
record the light wave amplitude (light intensity) in-
formation and phasic information and make the light
wave reappear[4]. In order to create holographic
negatives and realize stereo image reappearance,
a stable platform or a specific facility and environ-
ment is needed. That is the reason why it is not
widely applied in object 3D measurement.

2.7 Method based on magnetic 3D coordinate
measurement

By means of the electron-magnetic transducing
technology, the 3 space digitizer produced by Pol-
hemus Company, USA, can create magnetic field
around the object to be measured. Then with a
manual-operation feeler lever, it can measure the
3D spatial coordinates of non-mental objects point
by point. The biggest measuring object is 1.5 m
with a coordinate precision of ±0.8 mm. The high-
est sampling frequency is 60 point/s. The data can
be input to the computer directly. This device can
be used for body volume measurement, joint angle
relationship measurement, biologic isoline creation
and so on. Another device, 3 Space Tracker, may
be used for dynamic inspection, such as head action
tracking, gait and limbs action analysis, by linking
multiple sensor contacts to different parts of the
dynamic object. This technique does not need to
keep a clear “sight line” between the measured
point and the device. It is not affected by the sound
or laser facilities either, which can be applied in the
fields as biologic medical science and aerospace.
This kind of equipment is easy to operate and is of
a comparatively low price. But it can be only used
for non-mental small objects with a limited preci-
sion.

2.8 Method based on GPS

The GPS system is a powerful means to mensu-
rate the spatial coordinate of an outdoor point on
the earth’s surface[5,6]. In particular, it is used for
measuring point by point for sparse points in a wide
area, such as geodetic control, large-scale engi-
neering transformation, plate movement and dias-
trophism monitoring, and carrier (such as planes,
ships, vehicles and even people) action status
records. Though GPS still does not meet the preci-
sion measurement requirements of indoor large me-
chanic multi-object points, it does possess advan-
tages for specific outdoor industrial objects (such
as invisible objects or objects with a large span),
under the support of differentiate technology and
other technologies. The precision is between sub
mm level and mm level[5-7]. The portable GPS re-
ceiver loaded on an air object will be the optimal
strategy to determine its spatial action status when
it has enough sampling frequency.

2.9 Electro-magnetic wave distance measure-
ment method

The comparison between the visible distance rel-
ative precision of one million percentage distance
and that of the 300 percentage distance 30 years
ago is a good example to prove the rapid develop-
ment of electro-magnetic wave distance measure-
ment technology. In industrial measurement, there
are a large number of research and application
achievements on laser distance measurement tech-
nology[8-10].

It is feasible to use electro-magnetic wave dis-
tance measurement facilities in industrial measure-
ment. However, some issues should be paid atten-
tion to.

1) For the total station with distance measure-
ment components, the effect caused by the multipli-
cation constant may be neglected due to the short distance in industrial measurement. However, the effect caused by the addition constant is often intolerable. To decrease the effect, the direction with a higher precision (such as ± 0.1 mm) should be vertical with the distance measurement direction. For a common total station of ± (*2 mm + 2 × 10^-6 *D*), for example, if the point location precision of the direction that is vertical with the distance measurement direction is ± 0.1 mm, the rotation angle of the total station should be no more than 3°.

2) For the telemeter with the only function of distance measurement, the addition constant is not acceptable either. For instance, the random addition constant of ME 5000 may reach ± 0.2 mm. Such a kind of equipment is not able to measure the side length of the high precision industrial control net. Besides the problem of addition constant, the unfitness of the compulsory alignment between the clinometer and side measurement meter is hard to estimate.

3) Some short-distance scanners, such as TDS short-distance laser scanner produced by Kenichi Kamijo Company, Japan, belong to the non-object type. When the object distance is 90 mm, the resolution will be ± 0.3 mm. When the object distance is 3 m, the resolution will be ± 10 mm. But for a Cyrax laser scanner, when the object distance is 50 m, the resolution will be ± (2 mm-6 mm). There are laser telemeters to detect the surface processing precision of the mental components overseas. When the object distance is of several mm, the resolution will reach several 10 nm. (e.g. LC-2420 from Keyence co., Japan, it’s operating distance 10 mm, resolution 0.01 μm).

2.10 Method based on theodolite

In industrial measurement, sampling and detection, theodolite, electronic theodolite and total station and routine methods as forward intersection, backward intersection, indirect elevation measurement can be used. Each kind of clinometer with an error of ± 2”, ± 1”, ± 0.5” in the first-round measurement may accomplish some tasks in the short-distance environment. Some problems should be considered in the circumstances as compulsory alignment, the change of 2c and the corresponding measure in short-distance operations, design and usage of lighting, detection and sampling tools. As for the eyepiece system with CCD facilities, the clinometers which can automatically track the shaped object or can automatically and accurately align for known similar aspect are powerful facilities in industrial measurement.

2.11 Other industrial methods based on angle and distance measurement units

1) The structured light industrial section measurement method based on the laser theodolite is fit for the section measurement of some large machines or their components, especially for the internal structure measurement. The assembly of the project light beams of the known spatial direction is the structured light. According to the scanning equation of the laser theodolite with three free rotation degrees, the structured light produced by laser is taken as one direction of the forward intersection, while the observation direction of the electronic theodolite is the other, which will make the internal structure measurement with less texture go on smoothly.

2) The high precision industrial measurement control net is the infrastructure for the measurement, detection and sampling of batch quantity of workpieces. Compared with the “3D Industrial Measurement System”, it has apparent advantages on speed, precision and reliability, and has more apparent advantages over the operation based on spatial backward-forward intersection method. Much experience has been accumulated in the establishment and application of 3D control net.

3) For the horizontal section mensuration of large industrial objects, the approximation method of reflective coating and leveling method on the lifting platform can be used. However, both ways have disadvantages in either less precision or fussy operations.

2.12 Industrial photogrammetric method

The industrial photogrammetry is one of the three components in close-range photogrammetry. Research and application achievements from overseas
The industrial photogrammetry is an essential means, which is fit for circumstances as a multitude of points to be measured on the object, unapproachable object, motional object, object in the distortion status, concussion status, poisonous environment, and unstable sensor platform. In principle, the data of objects taken by the (grid) measurement camera, non-measurement camera and CCD (including CID, PSD) camera can be processed by photogrammetry later. According to the technical margin and demands, the relative precision may swing between one thousandth and one millionth. The technology of multi-station photogrammetry should be attached more importance to. To measure the antenna with the diameter of 50 m with CRC-1 camera, Autoset-2 automatic coordinate observation installation and 40 coverages of multi-station photographing, the point location precision may reach ± 0.05 mm. Carry out photogrammetric surveying with online CCD for the products on the assembly lines. Manipulate the robot arm to direct and select the product. The response time is within the range of 1/30 s. For the objects in the dangerous space and for the aerospace researches, long-range surveying may be carried out. Manipulation signals can be provided for the robot motion as well.

3 Principle to select industrial measurement methods and relevant problems

3.1 Optimal ultimate precision for some important measurement methods

It is important to select a suitable measurement method to learn about the maximum precision provided by the method in the optimal condition. The optimal ultimate precision $m_{\text{min}}$ based on angle-measurement unit (such as the forward section of electronic theodolite) is the product of the shortest sight length $d$ and error $m_a$ of the angular measurement, $m_{\text{min}} = d \cdot m_a$. If $d = 1.2$ m, $m_a = \pm 0.5^\circ$, then $m_{\text{min}} = \pm 3 \mu m$. Thus, to shorten the observation distance and adequately increase the clinometer level is the basic measure to guarantee the industrial measurement precision.

The “ultimate” high precision $m_{\text{min}}$ in photogrammetry is the product of error $m_{x,y}$ in image point location and image scale denominator $m : m_{\text{min}} = m \cdot m_{x,y}$. Thus, to increase the image construction scale and assure the image point location precision is the fundamental method in industrial photogrammetric precision. The assurance of image point location precision relies on the strict processing of image construction and image point coordinate surveying and measurement. Special attention should be paid to the application of multi-station pho-
3.2 **Application occasions for industrial photogrammetry**

1) The distribution of points to be measured is dense on the object. There are many points to be measured on an individual object;

2) The object is in environments as shaking, underwater, high-speed motion, poisonous or hard to approach, even if it is in a circumstance of few points to be measured.

3.3 **Application occasions for angle-measurement unit**

Angle-measurement unit as theodolite, electronic theodolite and total station are fit for occasions with sparse points to be measured but high precision requirement, or where it is unable or unfit to use professional sensors and photographing methods.

3.4 **Methods for objects without textures**

Objects without or with few textures are common phenomena in industrial measurement.

1) When the points to be measured on the object are sparse, it is suitable to use structured light project measurement method. For example, the laser theodolite will produce structured light and measure angles online with electronic theodolite.

2) If the points to be measured on the object are dense, it is suitable to use photogrammetric methods after projection textures (including raster, stripes and artificial textures), including digital photogrammetry based on digital photograph matching.

3) The method of combination of laser distance measurement without cooperative objects and automatic angle recording is one of the big trends in recent international development in surveying and mapping, though the relative precision is not high.

4) In real-time and quasi-real time photogrammetry, with the help of coordinate transferring components, the feature points of the industrial object can be measured one after another.

5) As the industrial object lacks texture, there are needs to design and produce specific symbols and sampling tools in the measuring, detecting and sampling processes, so as to determine the coordinate, detecting hole site and sampling of the industrial component.

6) The digital image matching technology cannot directly be used for industrial objects without or short of textures.

3.5 **Limited error problems in industrial measurement**

For an industrial object, only relative location and size of each part is concerned. However, the absolute geographic location is not concerned. As a result, the limited error relational expression in each measurement step has its distinctiveness, among which the limited error distinctiveness of industrial measurement has been discussed and studied in detail [28].

3.6 **Method selected for micro objects measurement**

The study on spatial shape and visualization of micro objects and even objects in the micro-world will be an important orientation for scholars and researchers on the field of surveying or measurement. However, the method based on image processing will be the only selection. The images include optical-micro images, electro-micro images, tunnel-micro images, holographic images, interference fringe images (such as Newton Ring) and so on.

3.7 **Method selected for active industrial objects measurement**

The objective of the active industrial object measurement is to measure the action status of the object. The objects include inspection on robot joint action accuracy, mensuration on air-throwing object action track, mensuration on ship model action status, mensuration on amplitude and frequency of machine concussion and so on. Time keeping is an important technique for active object measurement. With the help of relative software, the time keeping precision may reach ±0.01 s. The frequency of LED, the symbol for lighting, can be accurately con-
trolled. The online electronic clock may keep time very accurately. Technologies as Morie image processing technology, photogrammetry technology based on CCD, LED technology with controllable frequencies on the objects, lighting resources with controllable frequencies in a dark background and time keeping technology on the high-speed camera are all fit for the action status mensuration.

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Notes to Contributors

Contributions are welcomed on one of the following subjects or in related areas:

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- Physical geo-surveying
- GPS
- Geo-surveying
- Engineering surveying
- RS
- Photogrammetry
- Mapping apparatus
- Cartology
- Graphics

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