REMOTE 3-DIMENSIONAL MEASUREMENT SYSTEM BY THEODOLITE INTERSECTION

by

Anuar b. Ahmad,
Jabatan Fotogrametri dan Kartografi
Fakulti Ukur, Universiti
Teknologi Malaysia

Abstract

This paper presents a discussion on remote dimensional measurement systems (i.e. non-contact measurement systems) which are available in the market. Most of the systems used the principle of triangulation and the method of intersection and resection. The advantages, functions and the applications of the system will also be discussed in general.

1.0 Introduction

For years, conventional surveying instruments have been used for many instrument measuring and adjustment applications in conjunction with industrial surveying. In most cases, the application of the conventional and mechanical-optical theodolite is limited to that of an alignment instrument.

Today, great importance is emphasied on continues quality control in all fields, continuous production process and product inspection activities which reduce the incidence of rejects. These methods have been recognised and a great deal of corrections and re-working time can be saved. Technical advancements in electronic measuring and computing equipment have brought about the development of new, versatile methods for the determination of coordinates.

In recent years, many manufacturers of surveying equipment have developed the use of theodolite intersection for industrial uses. They have developed highly sophisticated instruments and portable data capture systems, which are capable of real-time analysis and presentation of data to 20 microns accuracy, depending on geometry and other conditions. This system is known as "remote dimensional measuring system".

2.0 Remote Dimensional Measurement

2.1 General

A common problem in manufacturing large components is the quality control of critical dimensions. The problem can easily be solved on a small item by means of coordinate measuring machines. These machines use delicate manipulator arms to gently contact the points to be measured and the x, y and z coordinates are determined by a series of linear scales and sensitive touch transducers. Resolution approaches 0.5 microns on the best machines. Newer machines are motor driven and computer controlled. Thus the measurement of small components poses no problem to the modern coordinate measuring machine which can easily achieve accuracies of one or two microns for objects up to a cubic metre in size.

When the item to be measured is larger, the cost of a coordinate measuring machine increases dramatically and alternative methods become economically attractive. A popular solution is to use a laser interferometer. Angular flatness and straightness measurement are possible with interferometric system through a combination of accessories. Unfortunately the interferometric concept is limited for measurement along the direction of the laser beam travels. Any interruption of the beam requires the measurement be repeated. Other alternative solutions include photogrammetry, tape and theodolite, and autocollimation. These solutions have serious drawbacks such as successive pressure during contact, delay in obtaining results or highly skilled operator requirements.

Thus the ideal solution for three dimensional coordinates determination of object is to use a "remote measuring system" (i.e. non-contact measurement). Such a system is portable and within short time remote measuring system can be set up and real-time dimensional measurement can be made. This system uses a minimum of two electronic/digital theodolites, desk top computer, printer and one known distance for scale determination. A trolley is used to install the electronic/digital theodolite, computer and printer, and this makes the system portable. The system can be used either on-line (i.e. theodolite is linked to the computer) or off-line (i.e. a data recorder is used for data acquisition).

2.2.1 Technique

The remote measuring system uses the principle of triangulation and the method of intersection and resection. Two electronic/digital theodolites are set up at known distance (r), at point A and B. The horizontal and vertical angles (θ_1, θ_2, ϕ_1, ϕ_2) are measured with the theodolites to a target of unknown coordinates. Then the coordinates of that point (x, y, z) in space is determined, using simple trigonometry. Figure 2.1, is an example of the system and point P is determined using the following formulae:-

$$Xp = r/2 \sin(\phi_t) [1 + (\sin(\theta_2 - \theta_1) / \sin(\theta_2 + \theta_1)] \text{--------------(1a)}$$

$$Yp = r \sin(\phi_t) [\sin(\theta_2) \sin(\theta_1) / \sin(\theta_2 + \theta_1) \text{--------------(1b)}$$

$$Zp = r \sin(\phi_t) [\sin(\theta_2) \cot(\theta_1) / \sin(\theta_2 + \theta_1)] \text{--------------(1c)}$$

If the coordinate of several points on an object are determined, then using suitable software, information about the shape of the object may be compared with working drawings or specifications. In particular, distances, flatness and parallelism, orthogonality of planes, diameters and centres of circles and other geometrical properties may easily be determined.

Before any measurement is taken the system has to be set up. There are two stages in setting up the system, i.e. orientation and scaling. In orientation two electronic/digital theodolites are set up at freely selected locations which represent the two end points of the baseline. The next stage is aligning the two theodolites. The baseline is used as the reference for all the horizontal and vertical angles. For scaling, both theodolites are pointed simultaneously to the two ends of a scale bar whose length is accurately known.

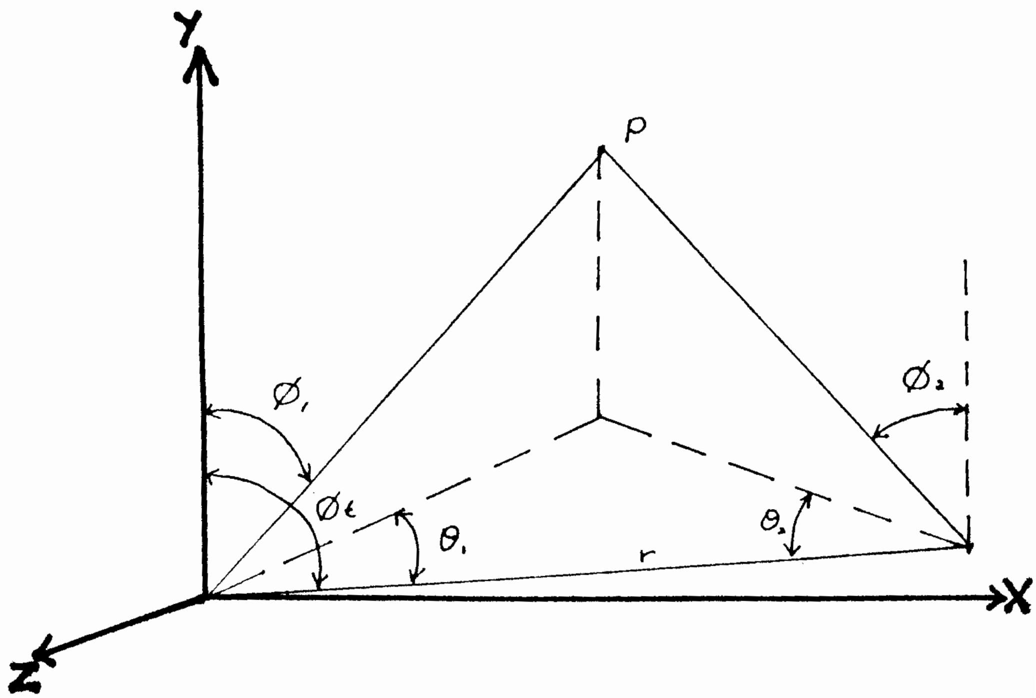


Figure 2.1 In the figure:-

ϕ_t is the zenith angle (if the theodolite are at uneven elevation).

ϕ_1 and ϕ_2 - - - - Vertical angles

θ_1 and θ_2 - - - - Horizontal angles

r - - - - - - - - - - - Horizontal distance

The setting up of the system depends on the type of the computer use and sophistication of the software. For example, using the software the separation of the two theodolites is determined by pointing to two targets at the ends of the scale bar such as using a subtense bar. The system can also handle two point problem or the inaccessible base. The software is also capable of transforming the coordinates to any reference point as the origin and any axial directions which are mutually perpendicular.

The computer controls the acquisition of the angular data and the pointing tolerances. Beside that, the computer produces real-time dimensional measurements from the data obtained by the theodolites.

2.2.2 Measuring Capacity Of The System

The coordinate measuring machine used in industrial measurement has a specific physical size. Usually the remote measuring system is suited for measuring large, medium and small objects with corresponding accuracy. The accuracy of the system claimed by the manufacturers is between 0.02 - 0.10 mm for small objects and 0.01 - 1.0 mm for objects having dimension of tens of metres.

2.2.3 Application Of The System

Since the system is portable and capable of measuring on-line or off-line the applications are unlimited. The following are some possible applications of the system:-

a. Dimensional control of large structures or fabrications.
b. Alignment of machines or components.
c. Deformation measurement of pressure vessels.
d. Volume determination of tanks.
e. Checking/assembling of aircraft or vehicle manufacturing jigs.
f. Calibration of large robots.

2.3 Description Of Present Remote Dimensional Measuring Systems

At present there are various systems developed by different manufacturers available in the market. Almost all the system used the same technique as described in section 2.2.1. The systems are as follows.

2.3.1 Wild-Leitz RMS 2000- - - (Remote Measuring System 2000)

The RMS 2000 uses the principle of triangulation (see figure 2.2). The theodolites are set up in a known relationship by pointing at each other and at a reference scale. From the measurement, the computer calculates the spatial relationship of the two theodolites, to provide a precise determination of coordinates on the object.

The RMS 2000 is available in two versions: one-line and off-line. For their measuring equipment, both versions use Wild T2000 and T2000S electronic theodolites. For the on-line version, a maximum of four electronis theodolites can be linked to a desk top computer driven by Leitz MESCAL software. Each theodolite is connected by a cable which provides bidirectional data transfer between computer and theodolite, and also supplies power to the theodolite. The computer fits on a trolley which acts as a storage unit and workstation. Targeting the theodolite at points on the object provides a series of measurements which are then transmitted on-line to the computer. These data can be compared with digitally stored parameters, to relate to the specified dimensions of the design, thus checking the quality of products. Similarly, deflection characteristics can also be

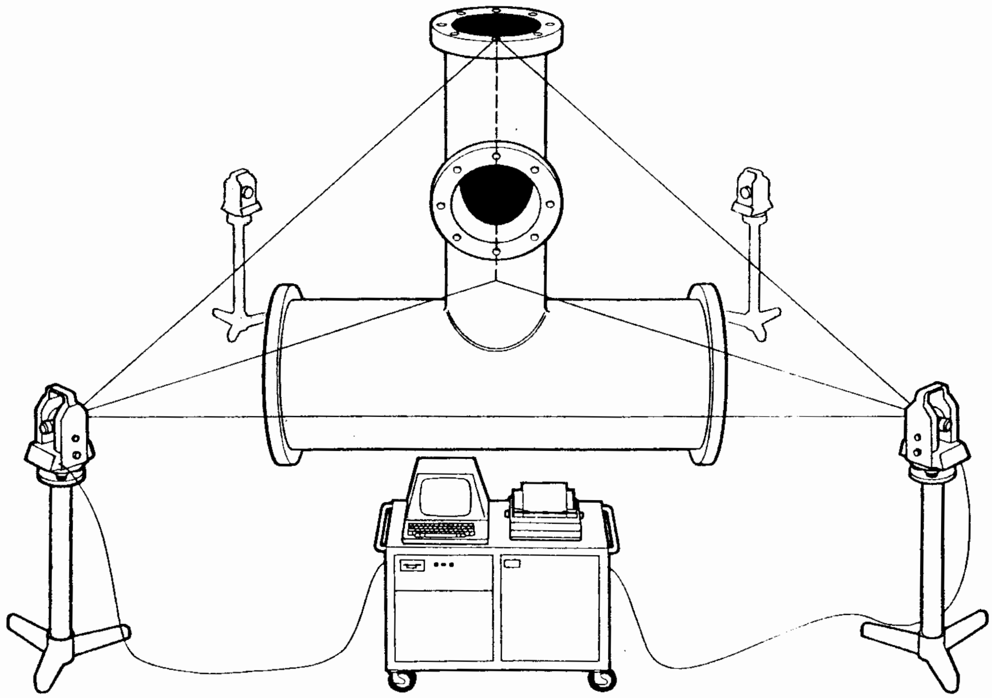


Figure 2.2 WILD-LEITZ RMS 2000

evaluated. The system can also make comparisons with standard models such as spheres, arcs, cylinders, planes or parabolas. All keys and displays on the theodolites are addressable from the computer and thus offer considerable operational advantages.

For the off-line version, two theodolites are linked to a Wild GRE 3 data terminal. This records the measured data and immediately computes the coordinate of the points. The measured data are then transferred from the Wild GRE 3 to the computer for further processing. By this means, the entire software used for the on-line system is also made available for the off-line system. The performance specification for the off-line system for the first time permits the use of a remote measuring system in extreme environmental condition i.e. from -20^{o} C to + 55^{o} C and at high relative humidity. A further feature of the off-line version of the RMS 2000 is that the system can be readily transported for use practically anywhere.

Before any measurement is taken, targets are located on the object. Then the theodolites are pointed to the targets. If the targets cannot be located on the object due to hazardous or other factors, a laser projection attachment can be used. The laser is fitted on one of the theodolites to project a laser spot on the object and the other theodolite is then sighted to the laser spot.

2.3.2 Kern ECDS 1 - - - (Electronic Coordinate Determination System 1)

ECDS 1 uses the principle of intersection (given either the coordinates of both positions of the theodolites or the length of the baseline and the height difference, see figure 2.3). Two Kern E2 are set up as explained in section 2.2.1. Then the points to be measured on the object are sighted with both theodolites. In conjuction with the stored baseline data and four angles received from the theodolites, the computer calculates continuosly the spatial X, Y, Z coordinates. As the result, the effect of height monitoring wrong sightings are detected. The operator can store the point coordinates together with the reference number and comments. In addition, this system allows analysis of coordinates of both surveyed points and theoretical reference points. A laser can also be used with this system as with the RMS 2000.

The ECDS 1 is available in two versions, on-line and off-line. Both versions of the system use either two Kern E1 or two Kern E2 electronic theodolites. For the on-line version, two Kern E2's are linked to the computer using data transmission cables with recording button. MICRO/PDP 11 of Digital Equipment Corporation is the computer used in the system.

For the off-line version, two Kern E2's are linked with a Kern ALPHACORD (i.e. field computer which can be conveniently hand-held or mounted on the centring head to turn with the theodolite). The data recorded in the Kern ALPHACORD is then transferred to the computer for further processing since the software for the on-line version can also be used for the off-line version.

2.3.3 Carl Zeiss Oberkochen Three Dimensional Coordinate Measurement

This system uses the principle of intersection (see figure 2.4). Two electronic theodolites (Zeiss ITH2) are sighted to the object. From the horizontal and vertical angles measured by the theodolites, the computer automatically calculate the spatial coordinates of the targeted points.

The calculation of the coordinates is based on the baseline which is determined before the measurement is taken. The alignment of the two theodolites and the determination of the baseline by means of a subtense bar are completed

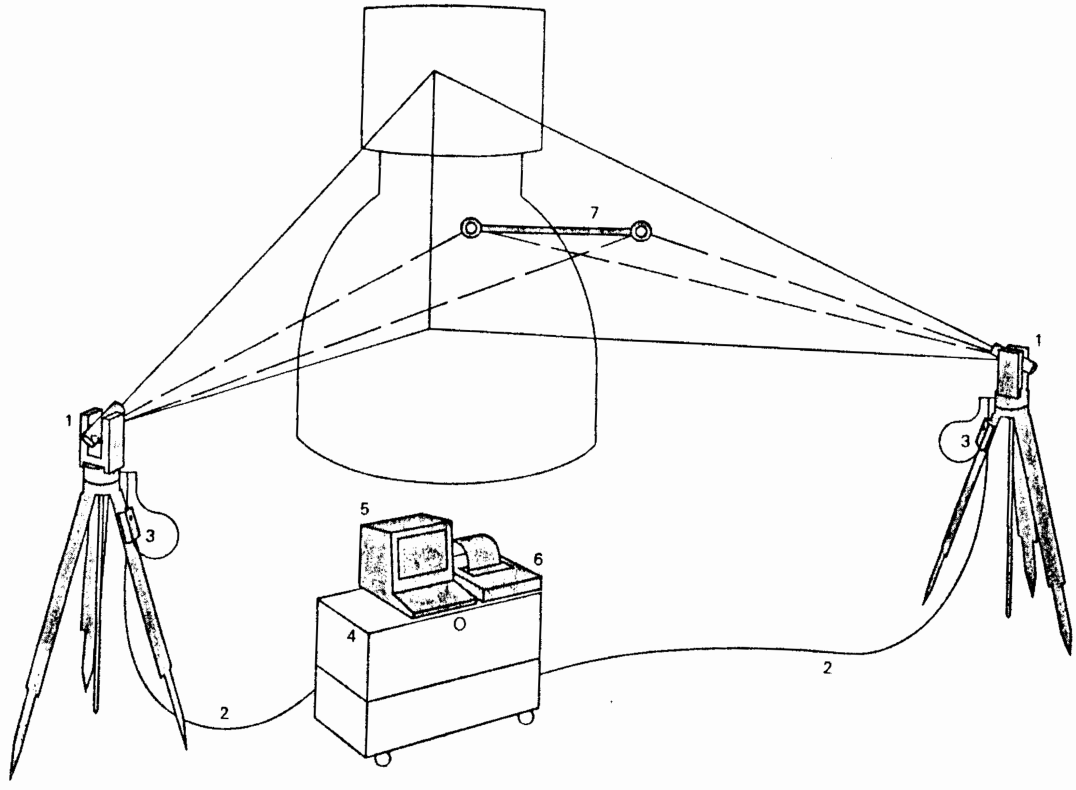


Figure 2.3 KERN ECDS 1 - Standard measuring equipment Two Kern E2 electronic theololites (1), two 20-meter supply and data transmission cables (2), two recording buttons (3), system-trolley (4), computer MICRO/PDP-11 with VT 220 (5), printer (6), calibration scale for the determination of the baseline date (7).

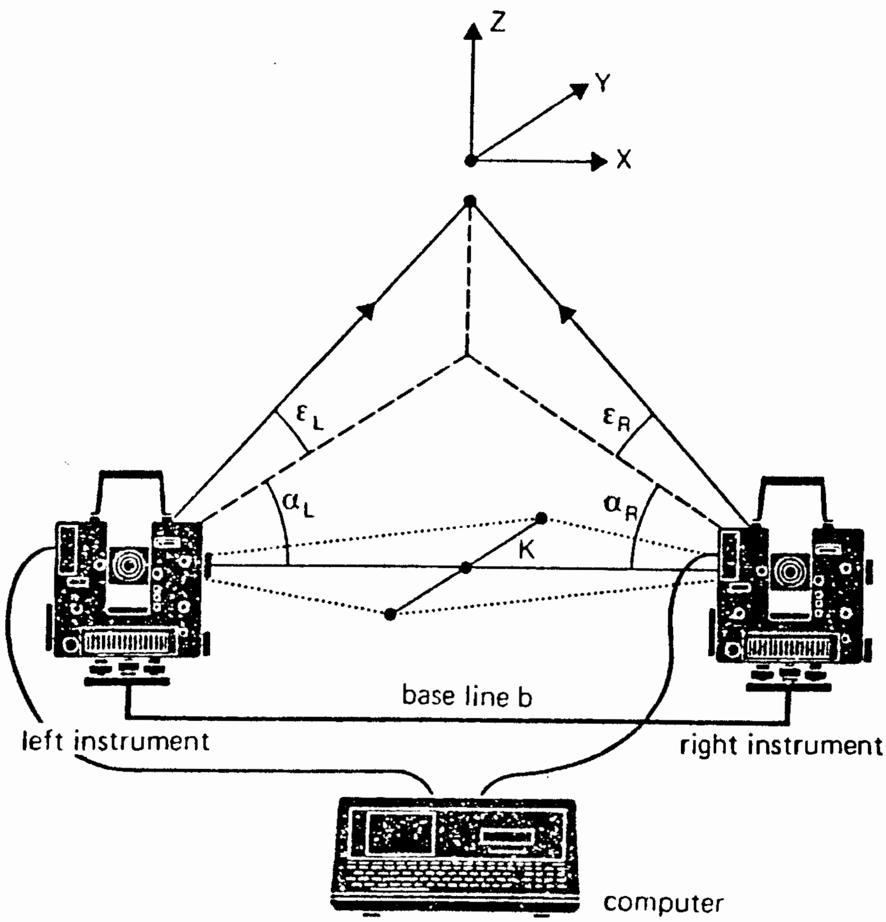


Figure 2.4 Carl Zeiss Oberkochen Three Dimensional Coordinate Measurement

within less than twenty minutes. The calibration of the baseline is determined using at least two points on the subtense bar.

In this system there is only an on-line version. The two electronic theodolites (Zeiss ITH2) are linked to the desk top computer (e.g. HP 85) using on-line interfaces. One subtense bar is used for the determination of the baseline. From the measurement the data are processed for the determination of regular figures, such as straight lines , circles, planes, spheres and cylinders.

2.3.4 Keuffel And Esser Aims R-T (Analytical Industrial Measurement System Real-Time)

AIMS R-T works on the principle of three dimensional triangulation (see figure 2.5). A known distance between two fixed targets and some elementary trigonometry provide the distance from the theodolites to the targets. In this system two or more DT-1 Digital Theodolite are used. The theodolites measure both horizontal and vertical angles and these are entered into a microcomputer to determine the three dimensional coordinates.

AIMS R-T performs real-time measurement to a user specified coordinate system. The system can perform target measurement in a non-gravitational oriented coordinate system, thus eliminating the necessity of physically levelling the object to make measurements relative to a "water-line". The theodolite may be shut down and restarted without loss of orientation providing they are not moved. This system can be used where the environment is hazardous or inaccessible. Only on-line version is available in this system. The AIM R-T software features a variety of most used application routines, with prompting of the operator through each routine such as parabolic fit, inverse routine, routine for circles, cylinders, spheres and hidden point.

2.3.5 Hewlett - Packard 3820A Coordinate Determination System

This system works on the principle of triangulation. Two digital theodolites 3820A are sighted at known points to measure angles. Both observe the same unknown points and perform accurate angle measurements. The 3820A's level compensator ensures that the horizontal plane is horizontal. Since the digital theodolite can measure both horizontal and vertical angles, a three-dimensional solution is obtained. Four angles (two horizontal and two vertical) are received from each unknown point for each 3820A theodolite. The four angles are combined to yield the three coordinates X, Y, Z of the unknown point.

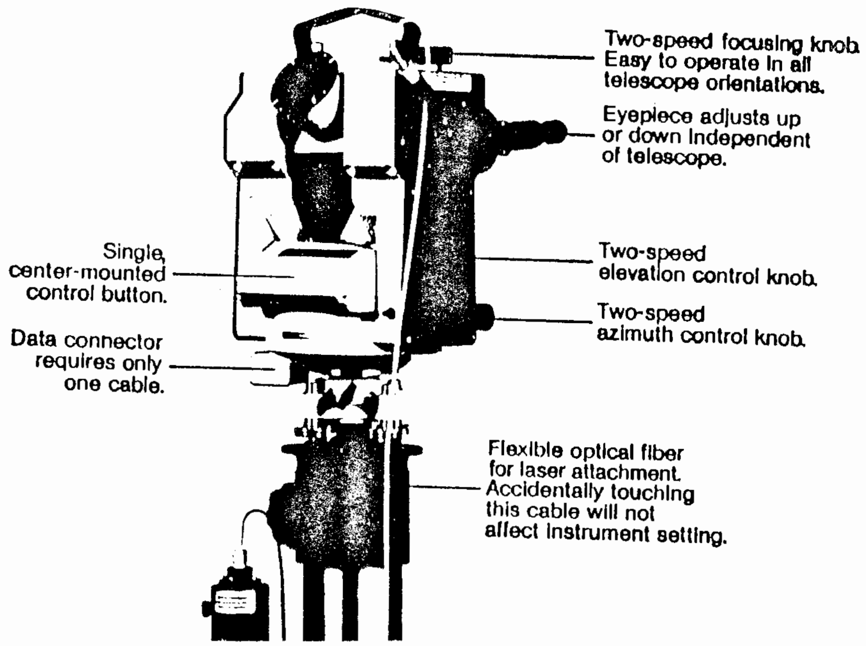
A HP 9845 T Computer/Controller is used in this system. The computer communicate through HP-IB interface. Only on-line version is available in this system. The HP 9845T is used to compute the coordinates of unknown points and also perform the function of data transfer, angle averaging (if additional sightings are made), graphics display of the measurements and operator prompting.

3.0 The Functions Of Remote Dimensional Measurement System In General

i) For quality assurance, measurements can be compared with norminal values.

ii) For measurement of large or small structures in site measurements can be taken and analysed againsts digital models.

iii) For alignment, coaxial elements can be set to precise coordinates.



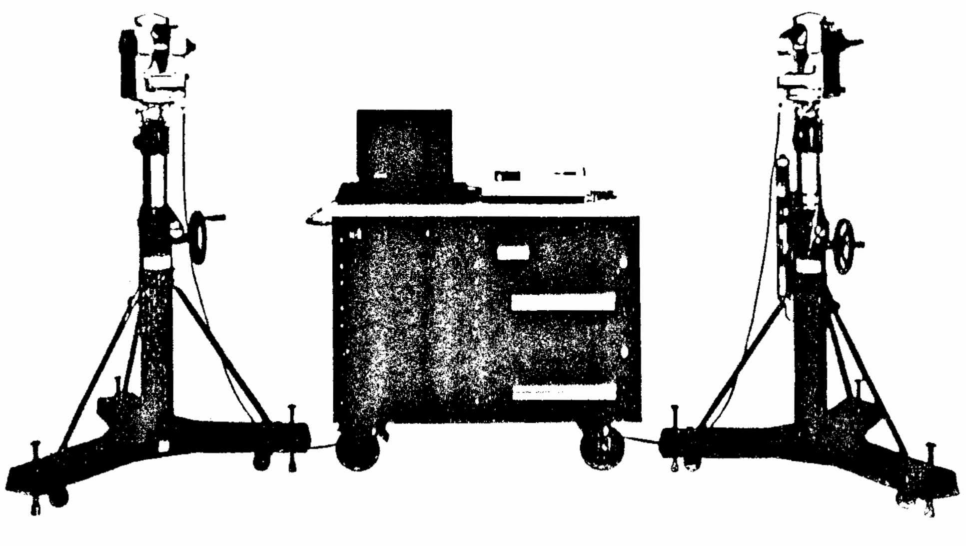


Figure 2.5 Keuffel And Esser Aims R-T - New AIMS II digital theodolite with one-half second accuracy. Top photo show advanced features that make AIMS II the easiest-to-use industrial theodolite on the market. Photo above shows the entire AIMS II system.

iv) For calibrations, the actual positioning of moving sub-assemblies can be determined and compared to their supposed position.

v) For layouts, the system allows design coordinates to be established for precise positioning of construction elements.

vi) For analysis of production qualify, trends in standard can be identified and corrected as needed.

4.0 The Advantages Of Remote Dimensional Measuring System In General

i) Accurate. The accuracy depends on the intersection geometry and accuracy of scaling. Typically it is 20 to 50 microns of 5m, 0.1 to 0.2 mm at 20 m.

ii) Mobile. The system can be taken to the object wherever it's located.

iii) Real-time measurement. Measurement are made quickly and instantaneously evaluated, thus preventing production hold-ups.

iv) Fast. Setting-up and data acquisition can be completed in a fraction of time required by conventional methods.

v) Simple. The system can be operated by factory personnel without surveying skills.

vi) Cost and time effective. By eliminating the need for master tools, gauges or jigs, the system can saves time and the expense of lifting equipment.

vii) Non-contact. The system enables non-contact measurements of sensitive components and objects in hazardous environments.

5.0 Applications Of Present Remote Dimensional Measuring Systems

5.1 Applications Of Wild-Leitz RMS 2000

(See figure 5.1)

a) Aircraft manufacture

b) Automotive manufacture

c) Tyre manufacture

d) Weapon manufacture

e) Civil engineering

f) Chemical engineering

g) Nuclear engineering

h) Shipbuilding

i) Power generation

j) Vehicle assembly

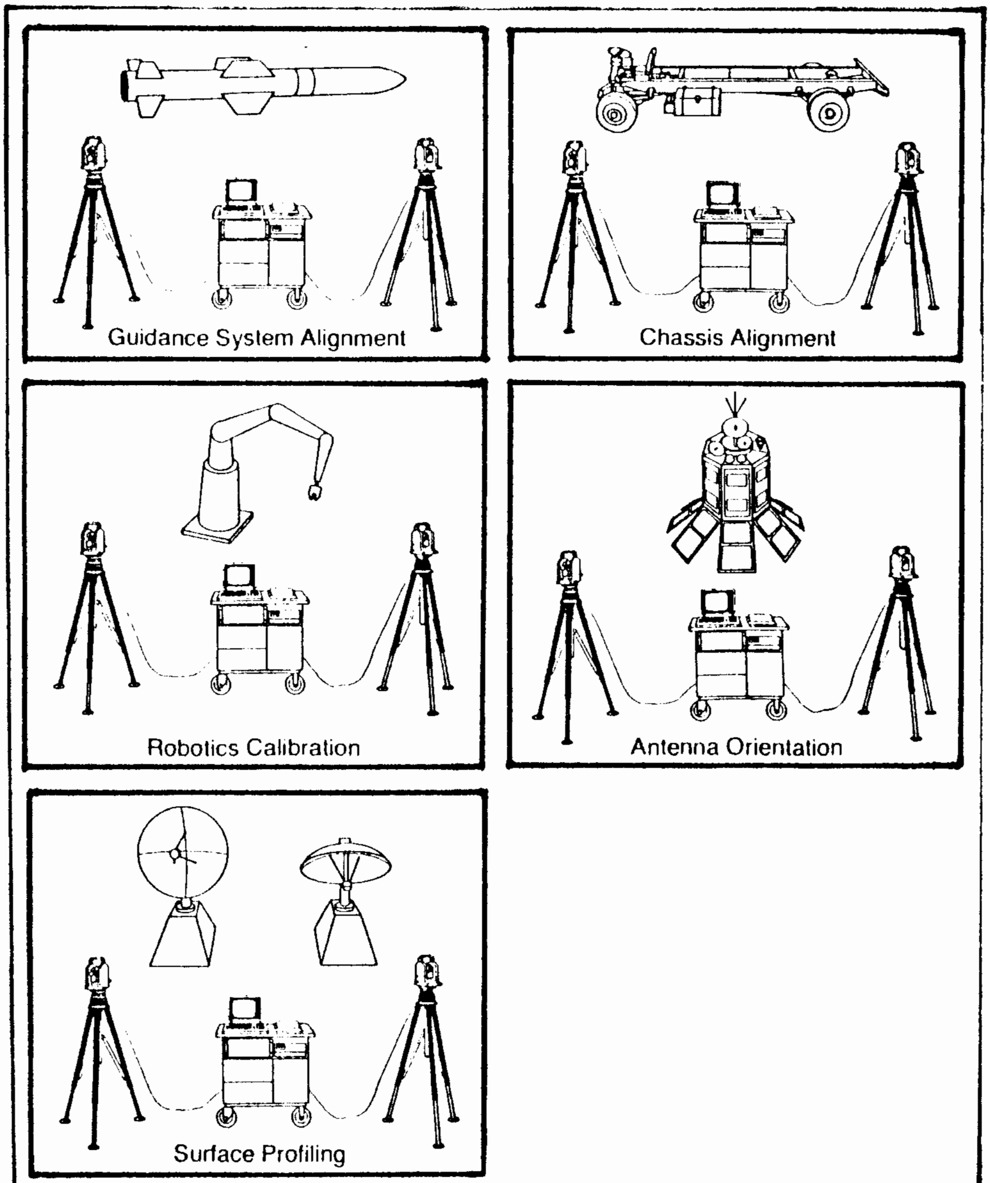


Figure 5.1 Figure showing part of the applications of Wild-Leitz RMS 2000

k) Space technology

l) Offshore oil construction

m) Industrial surveying

n) Robotics calibration

o) Chassis alignment

p) Antenna orientation

q) Surface profiling

r) Guidance system alignment

5.2 Applications Of Kern ECDS1 (See figure 5.2 (a) to (d))

a) Aircraft construction

b) Antenna construction

c) Tooling and general machine construction

d) Industrial surveying

5.3 Applications Of Carl Zeiss Oberkochen Theree Dimensional Coordinate Measuement

a) Aircraft construction

b) Shipbuilding

c) Vehicle assembly

d) Prefabricated components assembly

5.4 Applications Of Keuffel And Esser Aims R-T

a) Aircraft and aerospace manufacturing or rework

b) Shipbuilding and refitting

c) Automotive, truck and heavy equipment manufacture

d) Construction, structural or architectural

e) Power generation systems, generator, turbine boiler and pump alignment

f) Microwave and radar antenna manufacture and quality assessment

g) Tank and weapons manufacture, alignment and rework

5.5 Applications Of Hewlett-Packard 3820A Coordinate Determination

a) Aircraft inspection

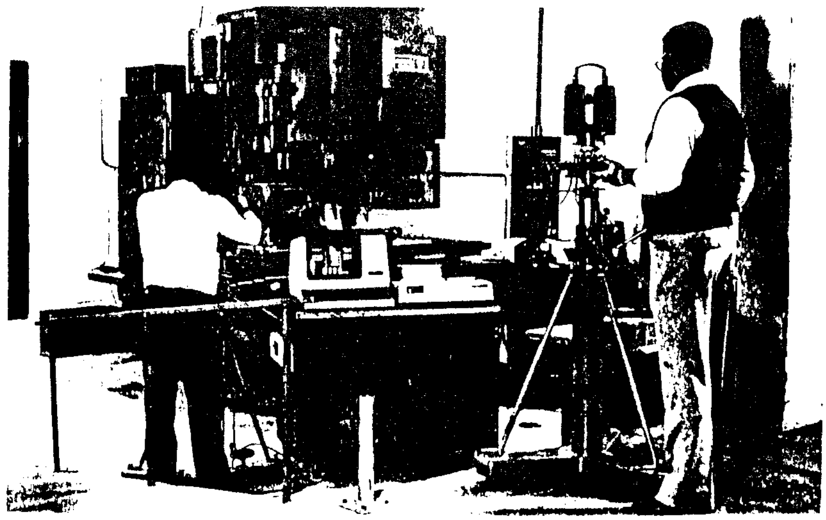


Figure 5.2 (a) Accuracy verification on a small 3D-coordinate measuring machine. The use of industrial tripods guarantees the highest degree of instrumentation stability.

Figure 5.2 (b) Using the ECDS 1 in research and development: Surveying and antenna reflector.

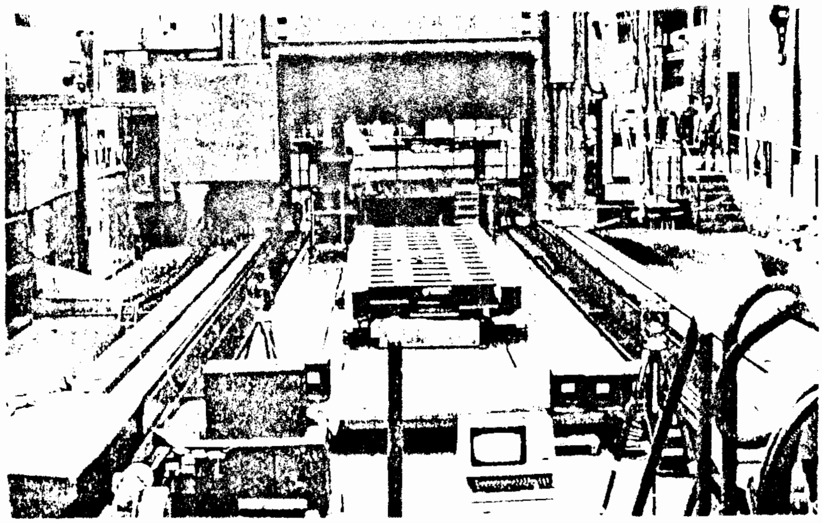


Figure 5.2 (c) Checking straightness, flatness and parallelism of the guiderails of a large CNC-tooling machine

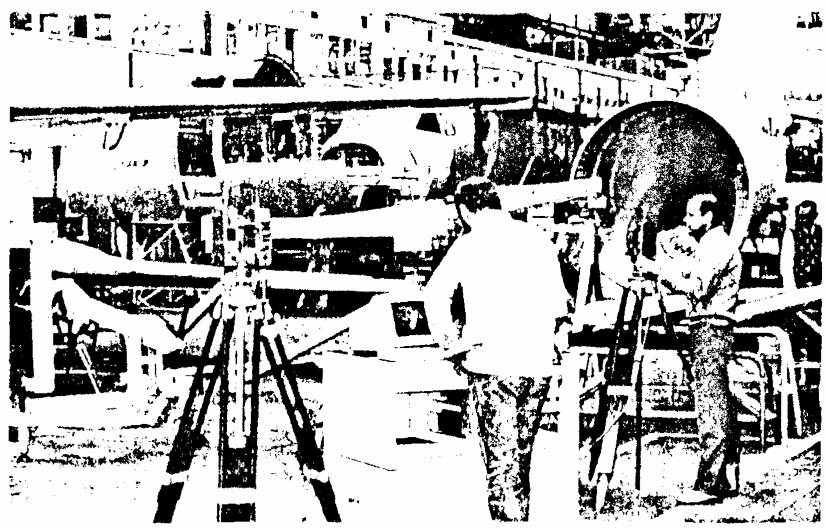


Figure 5.2 (d) Inspection measurements on various elements of the Fokker F28 aircraft

b) Antenna assembly

c) Deformation measurement of metal tank

6.0 Conclusion

From the discussion it is found that remote dimensional measuring system is a useful surveying instrument for industries such as for measuring, adjustment, calibration and so on, based on it's functions, advantages and applications.

References:

Ahmad A. "Three Dimensional Control By Theodolite Intersection" B. Sc. Thesis, University of Newcastle Upon Tyne, 1987.

A. Lardelli. "A Mobile 3D-Measuring System - The New Standard For Metrology And Quality Control". Kern & Co. Ltd. (Agent in UK - Optical and Mechanical Development Co. Ltd., Edeenbridge, Kent).

B.J. Karalvs. "Specific Applications Of Non-Contact Measurement - An Overview". Seminar on Industrial Application Of Non-Contact Measurement Organised by Joint Institution of Mechanical Engineers/Royal Institution of Chartered Surveyors, London, 5 March, 1987.

Douglas R. Johnson, "An Approach To Large-Scale Non-Contact Coordinate Measurements", Hewlett-Packard Journal, Sept., 1980.

Dr. H. Leitz. "Three Dimensional Coordinate Measurement By Intersection With Electronic Precision Theodolites". Journal of National Engineering Laboratory, Paper 4.1, NELEX 1982.

Dr. A. L. Allan. "The Principle of Theodolite Intersection Systems". Seminar on Industrial Application Of Non-Contact Measurement Organised By Joint Institution Of Mechanical Engineers/Royal Institution Of Chartered Surveyors, London, 5 March 1987.

M.A. Vyner and J.H. Hanold. "AIMS : An alytical Industrial Measuring Systems". Journal of Archives Of Photogrammetry, Commission V, York Vol. 24 Pt v/2 1982.

O. Katowski. 'RMS 2000, A System For Non-Contact Measurement Of Large Object". Wild Heenbrugg (UK) Ltd., Chatnam, Kent.

"Remote Dimensional Measurement By Theodolite", (brochure from The Royal Institution Of Chartered Surveyors, London).

"Kern ECDS 1, Electronic Coordinate Determination System" (brochure from Survey And General Instrument Co. Ltd., Edenbrigs, Kent).

"New Wild-Leitz RMS 2000 Measuring System", (Wild Heenbugg Reporter 23).

"Wild-Leitz RMS 2000 Remote Measuring System", (brochure from Wild Heenbrugg (UK) Ltd., Chatnam, Kent).