Electronic distance measuring

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As the geometry of buildings grows increasingly complex, recording their dimensions and those of the surrounding environment presents greater challenges to architects. This is particularly true for projects that are too small to merit a specialist-produced survey, or when unexpected factors affect the progress on site. Fortunately, technology, which has made great progress in recent times, can help. This article will review the various measuring methods and technologies available at present, with emphasis on handheld electronic measuring equipment.

Measurement errors

No measurement is exact, and all measurements will contain some degree of error. **Accuracy** is the nearness of a measurement to its true value. **Discrepancy** is the difference between two measured values of the same quantity. **Precision** is the consistence of a group of measurements.

There are three types of errors in measurement:

- **blunders** are fundamental errors that occur in the measuring process, usually caused by human error. Blunders are mistakes in the process of taking, reading, transcribing or recording survey data, for example recording 8.10m instead of 8.01m
- **systematic errors** occur when something causes a constant and consistent error throughout the measuring process. Systematic errors can be compensated for once the factor producing the error (for example, temperature or ground slope) has been identified.
- **random errors** are generally small errors that have no apparent cause but are a consequence of the measuring process itself. They result from the fact that it is impossible to get absolutely perfect measurements each time an instrument is read, for example, because of personal limitations of sight or touch. They tend to be compensating by

nature (ie, they are both positive and negative) and can be dealt with by statistical methods.

BS 5606: 1990 'Guide to Accuracy in Buildings' states that a site survey of a standard appropriate to the complexity of the project is of fundamental importance to its design and construction, but stresses that setting unrealistically high accuracy targets can add considerably to both time and cost.

Its recommendations in respect of accuracy in the use of measuring instruments for linear measurements are shown in Table 1.

BS5964 (see Further reading) provides guidance for site operations related to specific tasks (for example, dimensions to structural gridlines).

Distance measurement

Surveying can be defined as the accurate measurement of the relative position of both natural and man-made features. In the construction industry, surveying also involves the transferral of information from a virtual environment (drawings) to the real environment (the site). Although these two functions would appear to be the opposite of each other, in reality similar instrumentation and techniques are used for both.

The following techniques are available for distance measuring, in order of their accuracy:

- pacing
- tacheometry
- chaining
- electronic measurement.

Pacing is a simple means of measuring linear distance by walking. It is one of the oldest methods of measurement, and was used extensively by the Romans. The Roman pace was measured from the heel of the foot to the heel of the same foot in the next stretch (ie, two steps), and was roughly equivalent to 1500 mm in modern dimensions. In fact, the term 'mile' derives from 1000 ('mille') paces by a Roman legion. In the words of a modern comedian: 'Everywhere is within walking distance, provided you have enough time.' A practised individual who has calibrated his/her step can achieve accuracy of 1% (1/100) by pacing.

Tacheometry is an optical method for measuring distances whereby a theodolite, an instrument that can measure angles very precisely, is aimed at both ends of a target staff of known height. Once the angle between top and bottom measurements has been established, simple trigonometry is used to determine the distance to the staff. On the other hand, if the distance to a certain object, for example a building, is known, then the angle measurement can be used to determine the object's height. In the **Stadia** method, the telescope has a pair of cross-hairs built into the lenses. A calibrated staff is viewed through the eyepiece and the number of calibrations seen is recorded and, when this is multiplied by a constant for the apparatus, the distance is obtained. Accuracy of up to 0.2% (1/500) is possible when using tacheometry.

Historically, distance over the ground was measured by long poles or rods placed end to end. Poles were eventually replaced by chains, as these were easier to carry and more accurate. Thus arose the Gunter's chain of 100 links and overall length of 66 feet. Ten square chains are equal to an acre, so the Gunter's chain remains linked to area measurements to this day. The Gunter's chain was eventually replaced by the engineer's chain of 100 one-foot links, which was itself replaced by steel tapes. Although chains are no longer in use, the method of measuring with tapes is still referred to as **chaining**. The accuracy that can be achieved depends on the type of tape used, as different materials have different expansion coefficients and sagging properties, but can be of up to 0.02% (1/5000). For high-precision work, Invar (an alloy made of 35% nickel and 65% steel, with a low expansion coefficient) tapes are used. Taping must always be done horizontally: taping over sloping ground is done in sections, referred to as 'breaking the chain'. Common sources of systematic errors in taping are:

- stretching or distortion of the tape with constant use. Therefore, before taking measurements the tape should be compared against a standard tape. The standard tape is simply a tape that is used only for the standardisation of other tapes. It thus receives no heavy usage, and should not have deformed
- steel tapes are standardised for use at 20°C; higher or lower temperatures will affect the tape's length
- a tape is designed to be used with a specific amount of tension applied to it and if the tension is greater than standard, the tape will stretch
- when taping between two points, the tape is often suspended above the ground due to the height of the marker points. This results in the tape sagging. The shape of curve that a tape suspended at each end adopts is called the **catenary**. The curve adds to the measured length
- poor alignment
- when taping a distance on a slope, even a gentle one, the measured distance given by the tape is the ground distance, and because of the slope, this is slightly longer than the required plan distance. To correct this it is necessary to know the difference in height between the two points on a slope.

Electronic distance measuring (EDM) equipment measures distance using electromagnetic waves by computing the time difference between a transmitted pulse and the return pulse (after it has been reflected off the target) or, alternatively, the phase difference between a transmitted and a reflected beam of radiation. EDM systems are available using three different wavelength bands:

- microwave systems, with a range of up to 150km, are not limited by line of sight or visibility, but require two identical stations, one at each end of the measurement

Table 1: Accuracy in use of measuring instruments (linear dimensions) from BS 5606

Instrument	Range of deviations	Comments
30m carbon steel tape for general use	5mm for distances up to 5m 10mm for distances of 5–25m 15mm for distances over 25m	With sag eliminated and slope correction applied
30m carbon steel tape for use in precise work	3mm for distances up to 10m 6mm for distances of 10–30m	At correct tension and with slope, sag and temperature corrections applied
Electronic distance measuring (EDM) instruments (short range models) for general use	10mm for distances of 30–50m 10mm/10ppm (parts per million of distance measured) for distances over 50m	Accuracies of EDM instruments vary; distances measured by EDM should normally be greater than 30m and measured from both ends
As above, for precise work	5mm/5ppm	

- infrared systems, with a range of up to 3km, are limited to a line of sight and also by rain, fog or other airborne particles
- light wave systems use a laser and have a range of up to 2km.

The accuracy of EDM equipment depends on the type of system used, but can be as high as 0.0001% (1/1,000,000). EDM errors can be caused by:

- atmospheric factors that affect the speed of the electromagnetic wave – these can be corrected by calculation
- the instruments themselves, for example, the so-called 'zero-error', which is caused by the lack of coincidence between the mechanical and the electro-optical centres of the instrument. These errors can be corrected by calibration
- incorrect pointing
- insufficient voltage
- unsuitable signal strength
- non-compliance with the procedures in manufacturer's manuals and instructions.

BS 7334 Parts 8 and 9:1992 (ISO 8322-8:1992) set out procedures for the investigation of systematic errors inherent to EDM.

Total stations are a relatively recent development that incorporate a theodolite and an EDM system, allowing measurement of both distances and angles. **Laser scanning** is an even newer development, which scans over an area at predetermined increments and records a close net of three-dimensional points. This 'cloud' of points can subsequently be used to produce conventional survey formats (plans, sections, elevations, surface models, etc). Laser scanning is particularly useful in the survey of historic buildings, as it can scan complex forms that would be time consuming to record point by point.

Handheld devices

Perhaps one of the most revolutionary recent developments has been that of handheld devices. Originally, these were sonic measuring instruments, with fairly low accuracy, making them more an estimating rather than a measuring tool.

Laser-based handheld instruments were introduced 10 years ago. Earlier EDM equipment required a target to reflect the incoming beam, making measuring effectively a two-person operation, but newer generation instruments dispense with this need by reflecting directly off existing surfaces and allow one-person measurement (manufacturers estimate time gains to be in the region of 60%). Although the reflectivity of the target material affects the maximum distance that can be measured without the use of a target plate, most building materials are adequate (for example, white masonry has a reflection coefficient of 85%, smooth concrete 24%, etc).

Lasers (Light Amplification by Stimulated Emission of Radiation) have been used in construction for 30 years, particularly for levelling purposes, but this use in handheld measuring instruments is a development that provides architects and designers with a tool of unequalled precision and ease of use.

Lasers can be generated by several means, but the ones most commonly used in construction are generated by diodes, which can produce relatively bright beams of light with low power usage. Lasers can be visible beam, as the ones used in EDM, or infrared. One important characteristic of lasers is that as their beams are very focused and parallel, the size of the dot is comparatively small even at large distances (for example, a dot 6mm in diameter at 10m, 30mm diameter at 30m and 60mm at 100m). Because laser instruments project a visible dot on the target surface, uncertainty is removed regarding the correctness of the measurement point, making their use suitable when obstructions are present.

Laser beams are classified to take account of their potential to cause harm to skin and eye. Lasers in EDM are generally Class 2, defined as those emitting visible light for which the natural aversion response to bright light (including the blink reflex) prevents retinal injury, including direct viewing of the laser beam with optics that could concentrate the laser output into the eye, for example, binoculars.

More recent developments have increased the range to around 200m with accuracy up to +/–1.5mm (the use of targets is recommended for distances over 50m). They also provide additional functions such as: performing calculations (for example, calculating areas or volumes while measurement is in progress); memories for saving and recalling measurements; integrated level; indirect height measurement using Pythagorean functions, which is useful when measuring facades; built-in telescopic viewer, etc.

The full potential of handheld EDM tools is realised when they are integrated with other electronic devices by means of Bluetooth technology, mainly handheld PCs using CAD software. This integration allows the data collected to be downloaded directly into .DWG or .DWX files, with consequential benefits in accuracy and productivity. Anyone who has ever carried out a building survey, however limited, will know the annoying experience of finding out that the most important dimension, the one on which the whole setting-out hinges, is either missing or wrong. But with an integrated system as described above, the data can be viewed graphically when captured. Also, since all elements of the survey can be viewed as the data collection progresses, areas of limited or difficult access can be left until a time when access is less of an issue. Individual rooms can be viewed on completion of the data collection, and checks can be made easily to ensure that all the required features have been measured correctly, both dimensionally and in terms of orientation (for example, doors can be viewed to ensure that the direction of swing is correct).

Commentary

Architects have not been as quick as some other professionals to embrace the technologies described, perhaps because they tend to undertake site measuring sporadically rather than daily. Nevertheless, the advantages of electronic data collection are self-evident, particularly when integrated with handheld PCs, and no doubt the technology will soon catch on.

Further reading

Visit **www.disto.com**, or email your questions to disto.uk@leica-geosystems.com or call Stuart Ward at Leica DISTO on 01908 246245.

BS 5964 Measurement Methods for Buildings – Setting out and Measurement, Part 1: Planning and organisation, measuring procedures, acceptance criteria

BS 7334 (ISO 8322) Building Construction – Measuring instruments – Methods for Determining Accuracy in Use, Parts 1–10 (parts 6, 8, 9 and 10 deal with EDM instruments)

BS 7307 (ISO 7976) Tolerance in Buildings - Methods of Measurement of Buildings and Buildings Products, Part 1: Methods and Instruments (in particular, Section 2: Measuring methods for those measurements which can be carried on building sites only)

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Module 11

1) The accuracy of steel tapes is regularised at:

- ☐ A 15°C
- ☐ B 20°C
- ☐ C 25°C
- ☐ D 30°C

2) The size of a laser dot at 30m distance is:

- ☐ A 6mm
- ☐ B 10mm
- ☐ C 30mm
- ☐ D 60mm

3) Lasers used in construction are usually:

- ☐ A Class 4
- ☐ B Class 3
- ☐ C Class 2
- ☐ D Class 1

4) Systematic errors in measurement are:

- ☐ A Constant and consistent throughout the measuring process
- ☐ B Blunders caused by human error
- ☐ C A consequence of the measuring process itself, with no apparent cause
- ☐ D Compensating by nature

5) The accuracy of EDM equipment can be up to:

- ☐ A 1%
- ☐ B 0.2%
- ☐ C 0.02%
- ☐ D 0.0001%

The RIBA says …

The RIBA has recently strengthened its approach to CPD. Each corporate member is required to achieve the following each year: 35 hours of CPD and 100 points of CPD, keep a record sheet, and plan training via a professional development plan (PDP). CPD study is divided into formal (usually course work) and general study (distance learning, etc).
The RIBA will contact at random 5% of registered practices at the end of every year and ask to see record sheets and PDPs of every RIBA member in the practice. This distance-learning series can contribute significantly to the 50% of 'general' study requirement.

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October 2003 – Toughened glass doors and screens

Q1: b Q2: a Q3: d Q4: c Q5: b

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