Introduction to Field Digital Mapping for Geology and Geomorphology using EDM (Total Station) and GMT (Generic Mapping Tool)

version 0.21

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Part 1 Field Digital Mapping for Geology

1.1 Introduction

1.1.1 The idea of field digital mapping

When a geologist finds out something remarkable, the geologist should bring the fact back and tell it to colleagues and the public. Since there is no way to pack up an outcrop or landscape into a bag to carry them back home, the geologist should seek an precise, objective, and quantitative way to record what he or she found. Artistic drawing and photography are indispensable to visualize the facts with sensation, but they cannot be measured. Fine logs of such small outcrops as trench walls are one of the best ways for documentation of geologic facts. However, it's often difficult to maintain accuracy on an outcrop with irregular surface or to cover an area extending tens of meters. As well, it has been difficult to map the topography of an area of 1000~10000 m2 or more without losing precision in centimeters.

The targets and goals of the field digital mapping are:
- detailed topographic mapping
- precise log of an outcrop
- in a few m^2 to 100000 m^2 area
- 10 cm to 10 m spacing of points to measure
- precision in position and height less than a few cm

If the object is smaller, hand-drawing, small-format photography, or hand-specimen would work well. On the other hand, large-scale topographic maps and aerial photographs, or GPS are useful for larger objects. For those targets and goals above, a total station instrument at this moment seems to be the most effective device both for cost and time, and processing the data with a personal computer brings very effective output.

Total station instruments became the most common tools for practical surveying for its excellent efficiency. Surveying, from its origin, has worked for digital recording of points. The sophisticated equipment and it's usage are also essential for geologists, but surveying naturally aims more at engineering than physical science. Most surveyors know how to delineate a coseismic ruptures on the surface, but have little idea to map the deformation along the ruptures in 3-D.

Photogrammetry is familiar to us for the delineation of topography in large scale maps such as 24k quadrangle sheets. Now the analyses of aerial photographs are carried out digitally both for vertical or oblique shots. For example, topographic mapping less than 10 cm resolution is possible with 9-inch camera on a balloon or helicopter, but it is too expensive for geologists.

High-performance GPS is getting more affordable for geologists. A pair of dual-frequency receiver for differential kinematic method will attain a few centimeter accuracy in sub-minute

A Coseismic Pull-Apart Basin on the North Anatolian Fault
Associated with the August-17-1999 Izmit (Kocaeli) Earthquake

Figure 1.1.1 An example of a TS-GMT digital map. Notice right-lateral offset and pull-apart subsidence.

measurement. The cost is getting close to a high-end total station. The advantage of GPS is the ability to record absolute positions on earth's spheroid while a total station instrument cannot orient the north by itself.

Considering our goals and related techniques, surveying with a total station instrument is useful in such objects:

- Coseismic ruptures and associated deformation.
- Small scale fluvial channels and terraces.
- Outcrops including trench walls.
- Fault scarps and terrace risers.
- Offset topography and piercing points along faults.
- Topographic profiles and low-precision leveling.

1.1.2 Brief history (personal)

John Hamilton (U.S. Geological Survey, Menlo Park) has introduced a total station instrument to paleoseismology in late 1980s. The author worked with him in 1990 and 1991 in the San Andreas fault zone to learn the marvelously effective way of mapping. The method introduced in this short course is basically John's invention, as far as the author knows.

Before we use the total station instrument, a plane table has long been regarded as the best way to map a small area. The output of a plane table is just a low-precision analog drawing. Since a map is drawn directly on a sheet in a fixed scale, there was no way to improve the quality. [Though Wolf and Ghilani (2001) do not even mention about a plain table, it's still used and taught in Japanese geography institutes.]

Several paleoseismologists in Japan and Europe learned the use of the total station instrument from John Hamilton. However, it had been too expensive for most geologists in earlier half of 1990s. The author devised some ways to realize digital mapping before he got the instrument.

The most primitive way: Hand-level, staff, tape measure, stakes, and strings. Putting a baseline and mesh on the ground using stakes and strings, height of each node and necessary details in grids are measured and mapped on graph paper.

Second step: Automatic level with horizontal circle, staff, tape measure, and stadia rod. Azimuth, horizontal distance, and height difference are measured and recorded by hand on a notebook. The data were then input to PowerBook 140 and processed using earlier version of MS Excel and DeltaGraphPro. Anyway, it was digital.

Better way: Theodrites (horizontal and vertical circles) with tape measure, later with a laser distance meter. Hand-written records.

In late 1990s, total station instruments become much popular and affordable models [lower precision all-in-one models less than $10,000] are available now. You can easily measure hundreds of points and process the data in a portable computer. However, it might be useful to be able to practice digital mapping with low-technology equipment in various circumstances. The

idea of mapping and zeal for delineation are sometimes more important than the tools.

1.1.3 Scope of the course

Surveying is a very well established discipline and business. This short course does not aim at teaching surveyors routines. The most important factor for the surveying is to define the errors and then attain desired accuracy. There are many textbooks and PC applications to learn and practice good surveys. Please make good use of those textbooks and applications by yourself.

Instead, this short course will give you general ideas about how to plan, set up, and measure geologic phenomena out in the field. The fundamentals of the TS survey are quite simple. Its operation is very much straight forward as well as data processing. There should not be any blackbox. If a user understand the meaning of each operation, all kinds of TS instruments and applications will be ready for use.

1.1.4 Reference

P.R. Wolf and C.D. Ghilani, Elementary Surveying, 10th edition, An introduction to Geomatics, Prentice Hall, 900p., 2002.

User's Manual of your TS

GMT - The Generic Mapping Tools - Homepage, http://gmt.soest.hawaii.edu/ [Good help and tutorials]

1.1.5 Acknowledgement

The author should like to extend sincere gratitude to Leica U.S.A. in Salt Lake City for kind support of lending a total station instrument for the course, to William R. Lund, Utah Geological Survey for the organization of the course, to Michael N. Machette, U.S. Geological Survey for the warm attention and kind arrangement to realize the course. With the opportunities to work with John Hamilton, U.S. Geological Survey, in the San Andreas fault zone and on the Nojima fault, the source of 1995 Kobe earthquake, the author leaned many things about total station survey of active faulting. Many thanks to John.

1.2 Total station fundamentals

1.2.1 Parameters and calculation

A total station instrument (TS) is digital theodrites with an EDM (electronic distance measurement) instrument and a microprocessor (CPU). Theodrites measure the horizontal angle (Hz) and vertical angle (V) of the line of sight from the center of TS to the center of a target on a point to measure. The center of TS is at the intersection of the rotation axes of horizontal and vertical circles. The center of a target is at the intersection of the axis of the centering rod and the axis of tilting.

An EDM instrument is built in the telescope to measure the slope distance (SD) between the center of TS and the center of a prism (not the center of the target). CPU calculate the coordinates (E, N, H) in a rectangular system of the point under the target, with reference to the TS coordinates (E0, N0, H0) using the measured polar coordinates (SD, Hz, V), instrument height (hi), target height (hr), and several correction factors and constants (See figure 1.2.1).

1.2.2 Correction factors and constants

Scale correction factor (in ppm) is a sum of atmospheric correction (dD1 in ppm), reduction to mean sea level (dD2 in ppm), and projection-scale factor (dD3 in ppm). dD1 is a function of temperature, atmospheric pressure, and humidity. Input of dD1 is usually required. Most user manuals have diagrams to estimate dD1 from the three parameters. New TS can calculate dD1. You can easily calculate dD1 with the formulae below. In any case, thermometer and barometer are necessary to estimate dD1.

$$\Delta D1 = 281.8 - \left[\frac{0.29065 \cdot p}{(1 + \alpha \cdot t)} - \frac{4.126 \cdot 10^{-4} \cdot h}{(1 + \alpha \cdot t)} \cdot 10^{X} \right]$$

where:

$\Delta D1$ = atomospheric correction in ppm
p = atomospheric pressure (hPa)
t = ambient temperature (°C)
h = relative humidity (%)
α = 1 / 273.16

$$X = \frac{7.5\,t}{237.3 + t} + 0.7857$$

Figure 1.2.2 Formulae for atmospheric correction. Use MS Excel for calculation.

zenith
V = 0

Hz = 0

SD

line of sight

V

Hz

c-STN: Center of TS

hi

Station (STN)
(E$_0$, N$_0$, H$_0$)

HD

dH

c-UKP: Center of target

hr

Unknown point (UKP)

(E, N, H)

STN: geographic position of
the station
UKP: geographic position of
the unknown point
c-STN: Center of TS
c-UKP: Center of the prism on
the unknown point

Hz=0 **V=0**

c-UKP

c-STN

Hz=0 **V=0**

V **SD**

c-STN **Hz**

c-UKP

c-UKP=(SD, V, Hz) polar

c-UKP

SD

V

hr

c-STN

UKP

hi

dH

STN

HD

(E0, N0, H0) rect

(*SD, V, Hz*) polar --- to be mesured

(E, N, H) rect = (HD sin Hz, HD cos Hz, H$_0$+dH)

E = SD sin V • sin HZ

N = SD sin V • cos Hz

H = H$_0$ + SD cos V - hr + hi

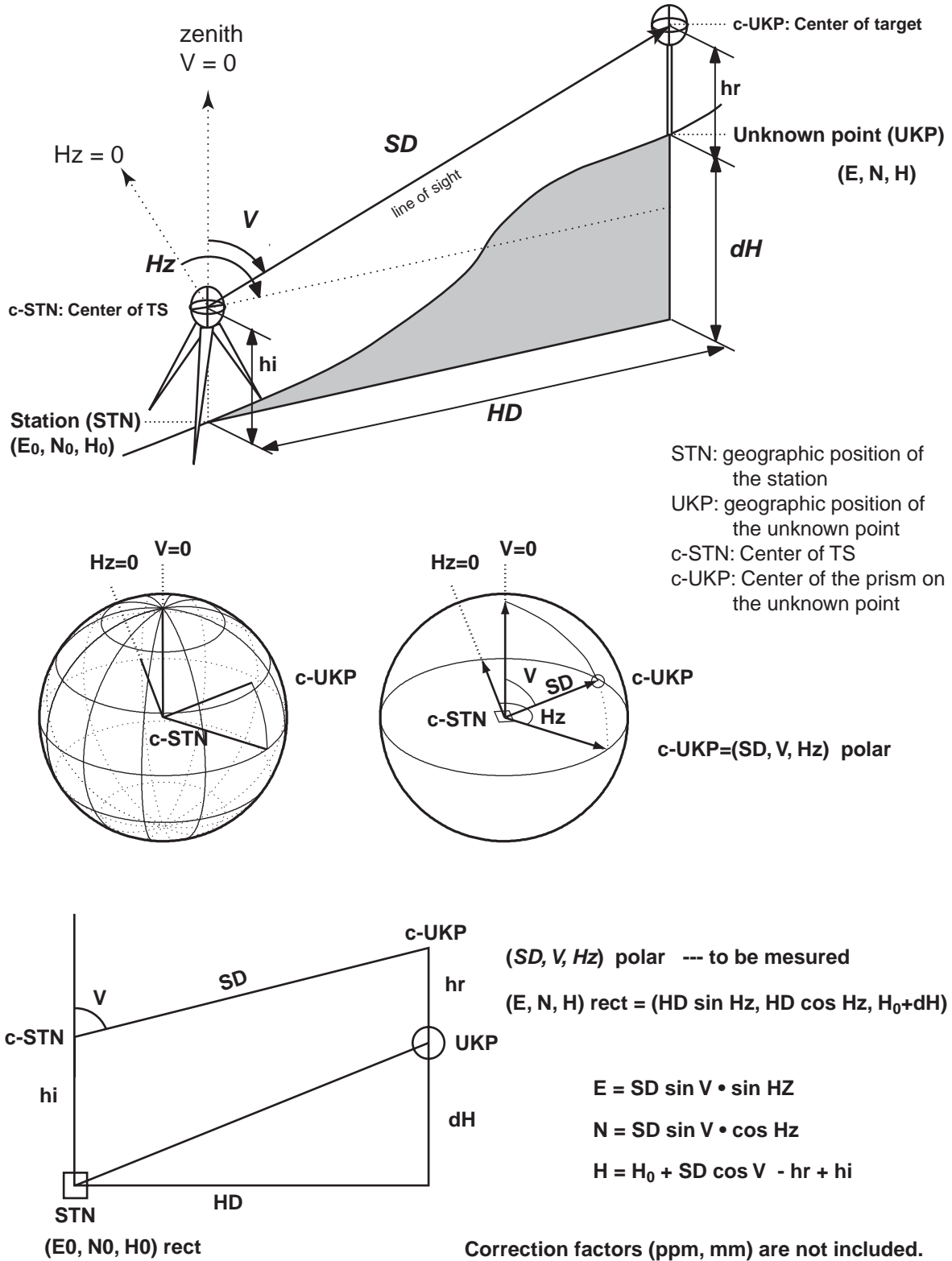**Correction factors (ppm, mm) are not included.**

Figure 1.2.1 Fundamental parameters and formulae

dD2 and dD3 are necessary to map in scale on the earth's spheroid surface at a particular geographic locality. If we do not pursuit geographic accuracy but site-specific accuracy, we do not need to include dD2 and dD3. Practically, the amount of correction derived from these factors are less than 100 ppm.

Prism constant is to be added to the distance measured by the EDM. The path of the laser between the source in TS and the optical center of a prism (reflector, target) is not the same as the true SD. Prism constant indicates the distance in millimeter to be added to (positive) or subtracted from (negative) the measured distance. Typically the constant ranges 0 to 50 mm. The mistake in setting this consonants results in much larger error than other factors. You must take much caution to use prisms of different constant at a time, or to use third party's prim. For example, 0 mm Leica prism constant is not applicable for Sokia TS.

For exact calculation of the distance and height difference, the curvature of the earth's surface and refractive index of the atmosphere are to be taken into account. See user's manual for the reduction formulae employed for the TS. CPU is programmed to use these formulae to give coordinates of measured points. When one recalculate rectangular coordinates from polar coordinates, one should use these formulae, however the difference is not very big.

1.3 Preparation for TS measurements

1.3.1 Precautions [Even if you do not operate.]

TS is very expensive and sensitive.

Always take the best care following "Do and Do not" below.

- Always carry a TS in a locked hard case even for a very short distance. Take the TS out of the hard case only beside a firmly set-up tripod.
- Do not move or carry a tripod with TS fixed on it except for centering.
- Use both hands to hold the TS handle.
- Never release the handle before the TS is fixed with tripod's fixing screw.
- Set up tripod as stable as possible.
- Keep tripod top, tribrach bottom and top, TS bottom always clean and away from any shock and impact.
- Take maximum care when tribrach is removed from the TS.
- Do not make TS very wet. Put on plastic cover and wait Or put the wet TS into the hard case and go home. Completely dry the TS as well as inside of the hard case immediately after returning to office or lodge.
- Do not check in at airport. Carry on the TS on board airplane.
- For courier service, put into a much larger box with perfect insulation. Buy enough insurance.
- Be careful to theft in automobile. Do not leave a TS in a car or in the field unattended. It has much resale value in market.

1.3.2 Equipment check list

A. Total station set

       [ ] total station instrument in hard case

       [ ] battery charger (AC, Car DC adapter)

       [ ] extra batteries

       [ ] memory module / card, serial cable

       [ ] rain cover

       [ ] user manuals

       [ ] tripod

       [ ] tape measure (2 m for hi and hr)

B. Prism set [1 or 2]

       [ ] prism

       [ ] prism holder

       [ ] centering rod

C. Backsight set

       [ ] prism

       [ ] prism holder

       [ ] prism carrier (to be fixed on tribrach, with optical / laser plummet)

       [ ] tribrach (to exchange prism carrier and TS)

D. Data processing

       [ ] Laptop computer with a serial port or USB port

       [ ] Serial cable and/or USB-serial adaptor

       [ ] Terminal application

       [ ] Application: MS Excel, GMT, Adobe Illustrator...etc.

       [ ] Data backup device and media (zip, memory card...etc)

E. Survey tools

       [ ] stakes, nails, paint, marker

       [ ] hammer

       [ ] thermometer, barometer/altimeter

       [ ] a pair of radio (with hand-free head sets)

       [ ] clipboard, field note, pen

       [ ] compass

       [ ] GPS

      A, 1 set of B, and E are indispensable all time. You can process the data back in the office, but it's better to arrange all data and make backup as soon as possible, before forgetting mistakes and details.

      With one backsight set, measurement of a backsight and traverse will be very easy and accurate. To occupy a new point, you need simply to exchange the parts above the tribrach. the position of TS center and target center above tribrach is the same after exchange.

1.3.3 Station deployment and set-up

Procedures and considerations before measurement are as follows:

1. Determine the area to measure.

First, be clear about what is important and necessary to map. Second, consider about point intervals and spacing for each object. Third, estimate the time and energy you need. The number of points to be measured in a day varies according to the circumstances (visibility due to relief, vegetation, and station location). Maximum 1000 points without any wandering about what to measure. Covering a rectangular area is good for map presentation.

2. Determine the positions of station(s) and backsight.

Find a station to measure the entire map area whenever it's possible.

When traverse is unavoidable, minimumize the number of station by finding the optimum location for stations.

Setup a station on a stable ground.

Do not face against the sun. The sun burns your eyes and TS.

1.3.4 Setting up a TS on tripod, centering

1. Stretch the tripod legs 10--15 cm shorter than their maximum length.

2. Open the legs to set the tripod head in front of operator's upper chest. When the TS is set up on the head, operator's eye should be slightly above the eyepiece. The instrument height is important for effective and comfortable survey. It differs from looking-down position and looking-up position. You should not touch or cling to the tripod during the survey.

3. At a new station without a reference point on the ground, level up the TS at an arbitrary point, where a stake can easily go in and be steady, and put down the stake at the center using the plummet.

4. To occupy an existing station above a reference point, first roughly level up the tripod head right above the point. For leveling up, a small level is useful. To find out the position, use a plumb bob or drop a stone through the hole in the tripod head.

5. Once roughly leveled and centered, push the each tip of the tripod leg firmly into the ground applying your full weight on the step above the tip. Apply the weight along the tripod leg without bending it.

6. Check the level and centering again. Adjust the level changing leg length.

7. Fix a tribrach with plummet, a tribrach and a prism carrier with plummet, or TS with built-in plummet on the tripod head.

8. Adjust tribrach's three screws to center the bubble of a spherical level.
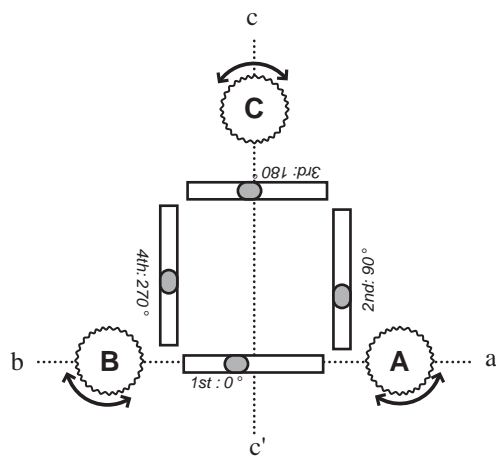
a. Release the lock of the horizontal circle.
b. Rotate alidade to set the plate level parallel to AB at 1st position.
c. Turn footscrews **A and B in opposite direction**, **the same amount** to center plate level. This adjust the tilt on ab axis.
d. Rotate alidade 90° ccw to set the plate level at the 2nd position.
e. Turn footscrew **C** to center plate level adjusting tilt along cc'.
f. Rotate alidade 90° ccw to set the plate level at the 3rd position.
g. Turn footscrews **A and B in opposite direction, the same amount** to eliminate half the centering error.
h. Rotate alidade 90° ccw to set the plate level at the 4th position.
i. Turn footscrew **C** to eliminate half the centering error.
j. Repeat b to i until the plate level is centered in all directions. [Take a little time for slow moving bubble in viscous fluid.]

Figure 1.3.3 Fine leveling up procedures.

9. Pull out optical plummet and use dioptric ring to focus at the graticule and then focus at the mark on the ground. Or, turn on laser plummet. Rotate the plummet or the TS (release horizontal circle lock) , to check it is centered within 1 cm from the reference point. If not, estimate the amount of offset and carefully translate entire tripod as much as the offset. Return to 4 and try to level and center again. The TS on the tripod head can be translated 1 cm from the center, therefore, rough centering within 1 cm is necessary. Be aware that the center of optical plummet or the laser point is on an axis perpendicular to the horizontal circle of the TS. If the TS is not level, the plummet line does not coincide with the plumb line.

10. Put the TS on tribrach if it is not there.

11. Use plate level or electronic level to finely level the TS following the instruction in figure 1.3.3. To adjust the electronic level, do the same as in the figure 1.3.3.

12. When the TS is finely leveled up, use the plummet to check centering. If the plummet center if off the reference point, slightly loosen the fixing screw below the tripod head and translate the tribrach to place the plummet center on the exact point.   Do not rotate. When the translation is done, tighten the fixing screw moderately. If the any portion of the base of the tribrach goes outside the tripod head, return to 4.

13. Rotate the TS by 180°. If the plummet center goes away from the point, slightly loosen the fixing screw and slide the TS halfway to the center.

14. Repeat 12 and 13 until the plummet center stays exactly on the center of the mark.

15. Tighten the fixing screw firmly without applying too much power. NEVER LOOSEN the screw until all measurements (of the day) are finished.

16. Measure the instrument height (hi). The center of the TS is marked on the side of the alidade. Vertical distance between the mark and the ground at the ground at the reference point is hi. Write hi down on notebook.

17. Check the plate level (or electronic level) from time to time during measurement before the TS tilts beyond the automatic correction. When you hit or push the tripod

hard check the level and centering.

1.3.5 Setting up a Backsight

A backsight (BS) is a reference point for horizontal angle. At the beginning of a new survey, a BS can be set at an arbitrary point and marked (see 1.3.4-3). The best way to set up a BS is to use a prism carrier and tribrach on a tripod (1.3.2-C). The procedures to level-up and centering of the prism are the same as TS (1.3.4). If there is no plummet in the tribrach and prism carrier, use the plummet of the TS and then exchange the TS above tribrach with a prism carrier.

In case the geometric position of a prism is very precisely represented, a prism on the top of a fencepost or on a corner on a boulder and an artificial object is taken as a BS. However, a prism on a centering rod sways too much around the center. A prism should be put right on the reference point when sighting is possible from the TS.

Measure the target (prism or reflector) height (hr) at the BS. Vertical distance between the center of target and the ground right beneath is hr. Write down hi on notebook.

In any case, both ends of the line between the station and backsight should be defined and represented as precise as possible.

When the station and backsight are ready, measure the azimuth from the station to the backsight using a compass. The azimuth is between 0° to 360° measured clockwise from north. Correct the magnetic declination to get true azimuth and record the true azimuth.

With a geologic compass, this may result in a few degree error in orientation. If very accurate orientation is needed, use surveyor's compass or a GPS receiver. Professional (carrier phase-shift) GPS receiver easily attain less than 10' accuracy on a 50 m baseline. Consumer (code-based) GPS receiver of 5 to 10 m error gives ~3° accuracy of orientation on a 200 m baseline.

GPS is useful to fix both orientation and geographic location of the TS measurement. Measure the station, BS, and the furthest points in four direction (N, E, S, W) more than 200 m apart both with a GPS receiver in UTM coordinates and with a TS. When you process the data after measurement, rotate and translate TS coordinates to best fit with the GPS coordinates and then plot on UTM grid. [Or, holding GPS walk straight from TS to BS. Read baring. (Michael's idea)]

1.3.6 Azimuth mark

An azimuth mark is a BS without a prism. Only the azimuth is measured from the station. An azimuth mark is a distal point or an object with a sharp and clear vertical edge to be taken as a reference of orientation from the station. It should be a geometric point or a vertical line without width to aim at without any error. At the same time, it must be so distinct that no confusion among other objects should happen. Once you find out a nice azimuth mark in the telescope, keep detailed sketch and comments in your notebook.

An azimuth mark may substitute for a BS for certain TS in case it's not necessary to define the errors. Some CPU and data processing applications do require BS measurement both for angles and distance, so be careful to take an easier way. Even when one sets up a BS, to set additional azimuth marks beside the BS is useful to check the configuration is not going wrong.

Use an azimuth mark like as a BS in 1.4.2-5.

1.4 Measurement

1.4.1 Start up the TS

When both the TS and backsight is finely leveled and centered, hardware and software setup of the TS begins. The procedures differs from one instrument to another. Follow the user's manual of each instrument. The list below show common important settings for most instruments. Most TS memorize these setting, but it's better to check through the setup menu in order not to have wrong setting.

System:

Choose appropriate existing interface for data output.

GSI output (Leica)--Use 8-digit ouptut and include E, N, H (81, 82, 83).

Angle/measurement:

Tilt correction / Compensator--2 axis

Horizontal angle incrementation--Right angle (clockwise)

Unit setting:

Angle--degree/min/sec or degree-decimal

Distance in m

Temperature in °C

Pressure in hPa

EDM setting:

Select IR Laser, Fine measuring mode. Use RL with caution.

Prism constant--Set appropriate value (1.2.2).

Atmospheric Parameters:

Get ppm from a diagram or let the TS calculate from hPa and °C.

Communication:

Set all parameters the same for TS and data logger/PC.

They are baud rate, data bits, parity, end mark, stop bits.

See manual for each device.

1.4.2 Setting up measurement

1. Turn on the TS.

2. Release both horizontal and vertical locks (knobs beside the round dials).

3. Some TS require to rotate the telescope 360° along the vertical circle to initialize angles.

4. Adjust the telescope to best fit to your eye: Using the inner ring (dioptric ring) of the eyepiece, make the image of the cross-hair sharpest and clearest (important).

5. [*Sokia only*] Rotate the alidade until the Hz angle reading is equal to the azimuth to the BS measured by compass (1.3.5). Then push HOLD key once. The Hz angle will not change until next HOLD.

6. Aim at the very center of prism at the backsight. For the coarse aiming, rotate alidade and telescope by hand using optical sight on or under the telescope box. Adjust focus using outer ring of the eye piece. When the prism comes into the sight and close to the center, lock the horizontal and vertical drives. Then use dials to aim exactly at the center, where corners of prism meet, of the prism.

7. [Sokia} Push HOLD again, then Hz reading changes according to alidade rotation. [Leica] Input the azimuth of the BS manually in measurement setup window.

8. If a station ID and BS ID are required, use 2 or 3 digit serial number (101, 102...) for each reference point. Use 4 digit serial number for unknown points.

9. Input station parameters hi, E0, N0, and H0. For new measurement, use (E0, N0, H0) = (1000, 1000, 1000) to avoid negative figures. If the coordinates are known, manually input the data.

10. Input the target height (hr).

11. Check the pointing at the prism again.

12. Use DIST key, make a BS measurement. Display Hz, V, SD, E, N, H and record them by hand with a sketch of the plan. Hz, V, and SD are raw data. It is possible to recalculate with new correlation factors with these raw measured data. Hz, E, N, and H are indispensable for traverse and reoccupying the station.

13. Create a new job or open an existing job

A job is a block of data sets stored in the memory like a file. One can create a new job or append data to existing job. A job name is used as an output filename in new Leica TS with .gsi extension, so a name with 8 characters of alphabet and number is safe. For example, UT051001 for the first job in Utah, May 10th.

1.4.3 Use hands and notebook

You can record all numerical data and a little text data in the TS, but descriptive information and graphic information should be recorded in your field book. Following is a suggested list for your survey records.

1. Place, date, time
2. Surveyor's name
3. Temperature, atmospheric pressure
4. Station coordinates: (E0, N0, H0), UTM by GPS, and hi
5. Backsight coordinates: (SD, V, Hz), (E, N, H), UTM by GPS, hr.
6. Azimuth mark Hz. Sketch of telescope view.
7. Sketch map of the sight and measured objects.
8. Description of measurement,

Point ID number (from--to), object, hr

Repeat this for each discrete object, or a group of points measured with different prism height (hr: This must be input to the TS each time it changes. Forgetting this is the

most common mistake. Be prepared.).
9. Backsight coordinates measured again at the end.

1.4.4 Radial shooting

From a station, we measure as many objects as possible within the sight. This method is called radial shooting.

The objects are classified as points, lines, and planar features. Each object is expressed as either a point or a group of points. Each point is recorded as coordinates with point ID number.

Points:

Backsight, new station, existing monuments

Linear features:

an edge of a fissure and crack, crest and toe of a scarp, axis or both sides of a stream, a road, fence, stratigraphic boundary on an outcrop, fault, perimeter of a trench, topographic profile...etc.
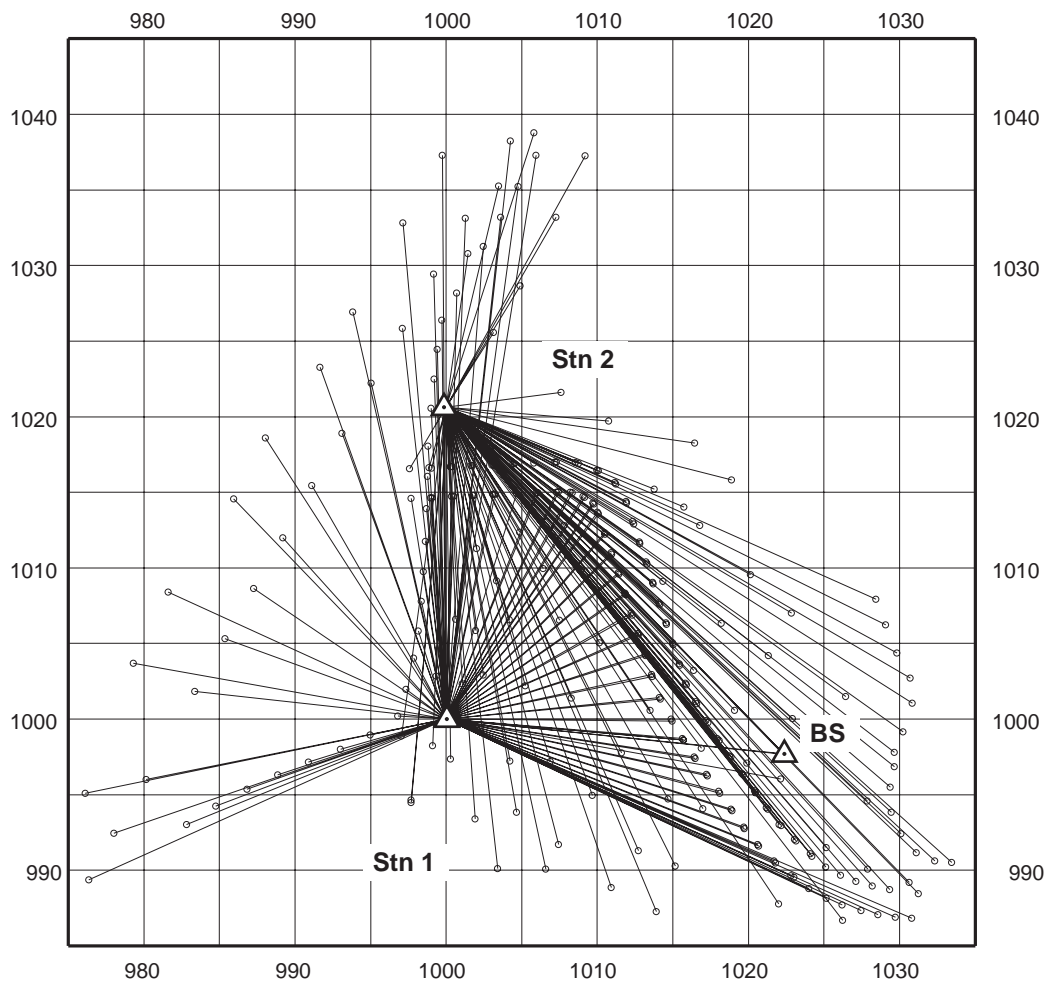

Figure 1.4.4 An example of radial shooting from Stn1 and Stn2.

A group of points on a discrete line should be measured consecutively for the sake of plotting. The pair of the first and last point ID number is necessary to separate the line from the other ones.

Smaller intervals of points result in more accurate records of the shapes. The balance between scale of the map, importance of the objects, and time and the purpose of the measurement will determine the interval needed. For example, if one measures an offset road across a surface rupture, the intervals should decrease toward the rupture as 2, 1, 0.5, 0.2, 0.1 m. Details are important inside the fault zone, but not outside.

Planar features (topographic mesh):

deformed ground surface, terrace surface, scarp slope…etc.

Regularly distributed points are essential for reliable representation of the surface geometry. 4 or 5 m mesh is usually good for wider area. Smaller spacing for important objects. See figure 1.1.1.

During the measurement, repeat BS measurement or azimuth check regularly, for example every 50 points to see there is no change in geometric configuration. Loose fixing screw or tripod bolts, shocks to the tripod, or tripod on soft ground may result in the shift of the TS and BS. An error should be within a few millimeters. Difference in a few centimeters indicates troubles. Discard the data possibly affected by the troubles and measure the BS again carefully.

1.4.5 Outcrop mapping

Mapping an outcrop like a trench wall is radial shooting on a steep wall. Use resection program to record the map on XY plane. Resection program calculates the station position from two known points, such as (0, 2) and (10, 2) grid nodes on trench wall. See user's manuals. Use a small target the center of which is set right in front of the point to measure. Shallow angle to look into a narrow trench and inaccurate prism positioning.

Machette's hybrid mapping: Michael Machette, U.S.G.S. developed combination of hand-drawing with TS measurement for accurate mapping on irregular trench wall with holes and bumps. Coordinates on the graph paper are measured by TS and plotted by hand. Details are drawn by hand to fill between the measured points. Mapping a trench wall only with TS often results in a map without details and reality. This hybrid method is good for both accuracy and reality of the logs.

1.4.6 Traverse

When it is not possible to view the entire mapping area from the first station, we traverse to a new station and repeat radial shooting. Adjusting the coordinates and orientation of the second station, measured coordinates from multiple stations will be in unique system. Most TS have a program for traverse.

1. Setup a prism on tripod, tribrach, and prism carrier centering on a mark on the ground. BS point may be used as a new station.

2. Measure the new station and record (E1, N1, H1) and Hz1 angle. Both in memory and on notebook. Turn of the TS.

3. Leaving the tribrach on the tripod, exchange the TS above tribch with the prism on prism carrier.

4. Exchanged TS and prism should be close to leveled and centered. Carefully apply small adjustment for fine leveling and centering.

5. Turn on the TS on the new station and point at the prism.

6. Run a traverse program or do following.

7. Input station coordinate (E1, N1, H1) and new hi (previous hr).

8. Pointing the center of prism, set Hz0 as Hz1+180 (Hz1 < 180) or Hz1-180 (Hz1 > 180). Use previous station as new BS.

9. Input new hr and measure. The coordinates of the 1st station must be (E0, N0, H0). The error must be less than a few millimeters.

10. To define errors and evaluate accuracy, follow standard procedures for surveyors.

1.5 Data retrieval and arrangement

1.5.1 From TS to Mac/PC

Use a serial port (RS232C for PC), or serial cable adaptor (RS422C for old Mac) or Serial-USB adaptor to connect to typical RS232C 9 pin female connector from TS. Release the serial port from other drivers for modem, apple talk, printer, scanner and so on.

Set the parameters of serial data transportation on TS and Win/PC the same. Use communication setup in TS and in termination application. Typical parameters are: 9600 baud, 8 bits, No parity, 1 stop bit, and Xon/Xoff. Both end of the connection should be set to the same for communication.

Make the Mac/PC application ready for receiving data and save the log, input send command to TS. Received character strings will be scrolled on the log window. When the last point ID is shown and scrolling stops, save the log as a text file.

1.5.2 Processing text-base data

The received data is in a text file like below. <CR+LF> is a MS-DOS style line break. Using MS-Excel, or sed and awk point id numbers, measured parameters, and coordinates are to be cut out. Spending a few minutes with MS-Excel will solve the problem. Unless recalculation from observed data SD, Hz, and V is needed, point ID, E, N, and H are necessary. Prism height is usually recorded. Compare the data file with your notebook to see all change in hr is correctly recorded. Missing adjustment result in sudden increase of height.

[Sokia Printing format]

```
OBS F1 0003-6000    S.Dist 220.610      V.obs 93-49'50"     H.obs 225-08'30" <CR+LF>
                    Code BS <CR+LF>
POS TP 6000         North 1844.739      East 1843.969       Elev 1984.297 <CR+LF>
                    Code BS <CR+LF>
```

We need: 6000, 220.610, 225.1416667, 93.835056, 1843.969, 1844.739, 1984.297

(No, SD, HZ, V, E, N, H)

[Leica GIS format]

```
110005+00001001 21.324+09554200 22.324+10144350 31..00+00022985 81..00+01022385
82..00+00997685 83..00+00995514 51..1.+0003+000 87..10+00001300 88..10+00001492
<CR+LF>
```

This format is much smarter than Sokia's. (81, 82, 83) = (E,N,H), 51: ppm, 87: hr, 88: hi

We need: 1001, 22.985, 101.7430556, 95.9116667, 1022.385, 997.685, 995.514

1.5.3 Correction and annotation

If necessary, remove bad data and correct H using right hr.

Input annotation for each point. Be sure to give different annotation to different segment of lines. Save and make backup copies.

Do these works as soon as possible, ***desirably before beer.***

```
        road               1117        993.833    1026.932     999.193
        road               1118        997.161    1032.817     999.126
        road               1119        999.752    1037.274     999.324
        road               1120       1022.152     996.031     995.359
        BS                 2001       1020.645     979.355     999.999
        BS                 2002       1020.646     979.356     999.999
        BS                 2003       1020.645     979.356     999.999
        STN1               2004       1000.000    1000.001     999.999
        STN1               2005       1000.000    1000.001     999.999
        step_east(NtoS)    2006       1022.382     997.678     995.366
        step_east(NtoS)    2007        997.597    1016.572    1000.299
        step_east(NtoS)    2008        998.862    1016.633    1000.279
```

Kan-pai!

[PART 2 on GMT is prepared in PDF format.]