13th International Workshop on Laser Ranging
"Toward Millimeter Accuracy"

Local Surveys for SLR:

A Primer

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Theory of Survey Observations

- A measurement or observation is considered indirect
  - combination of physical operations
    - instrument set up, instrument calibration
    - pointing
    - reading
    - corrections
- Always be an element of uncertainty

Observations and Errors

- Theory of observations
  - "Error" refers to difference between measurement and "true" value
- Errors are considered to be of 3 types
  - Blunders or mistakes
  - Systematic errors
    - sometimes human factor
  - Random

Accuracy and Precision

- Accuracy refers to closeness of measurement to the “true” value
- Precision refers to the closeness of measurements to each other in a set of repeated measurements
- *Possible to be precise but not accurate*

Estimate Measurement Quality

- Arithmetic Mean
- Mean Deviation or average error
- Standard Deviation
  - square root of the variance

- Least-squares adjustment

Distance Measurement

- Defined as the distance between two random points in 3-D space
  - usually measured as “slope” distance
- For computations:
  - reduced to horizontal
  - reduced to sea-level

Distance Measurement Methods

- Tapes
  - Generally used for very short distances, where systematic errors are minimized
    - expansion, tension, sag, not horizontal
- Electronic Distance Measurement (EDM)
  - Used for longer distances : up to 1 kilometer
  - Electro-optical: light waves
  - Electro-magnetic: microwaves

EDM Instruments

- Most common EDM use lightwaves
- EDM target is a corner cube of glass, often called a prism or retro-reflector
- Accuracy of +/- 1 mm + 1 ppm
  - Some very high-quality (very expensive) have sub-mm accuracy. 2-color instruments
- Correct for atmospheric conditions
  - temperature, pressure and humidity

EDM Systematic Errors

- Position of electrical center of transmitter
  - Instrument constant
- Position of effective center of retro-reflector
  - Prism constant

- EDM Calibration baseline used to determine instrument constant

Direction Measurement

- Directions are measured with a theodolite
  - Horizontal directions measured clockwise
  - angle computed as the difference between 2 directions
  - Vertical directions measured from zenith
- Most modern instruments are electronic
    - digital readout
- Standard deviation of 1 second of arc or less

Wild Theomat T3000

with Wild DI2002 EDM

Leica TC2003 Total Station

Leica NA2 Automatic Level

Theodolite Instrument Errors

- Instrument errors due to imperfections or non-adjustment are systematic
  - can be eliminated or reduced to negligible amount by proper procedures
  - Collimation error - line of sight not perpendicular to horizontal axis
  - Horizontal axis not perpendicular to vertical axis

Theodolite Instrument Errors

- Level vials out of adjustment
- Line of sight not coincident with optical axis

- Direct and reverse telescope pointing compensates for most errors
- Level vials should be adjusted
  - not a problem except for high vertical angles

Other Errors in Measuring Directions

- Human errors
  - eccentric set-up, instrument not level
  - not sighting precisely on target
  - parallax, imperfect focusing
- Natural errors
  - unequal atmospheric refraction
  - unequal expansion of instrument from sun heat

Vertical Distance Measurement

- Measurement of a vertical distance is called leveling
  - difference in elevation
- A “level” surface is curved surface normal to the plumb line or datum
  - common datum is Mean Sea Level
- Local surveys most interested in relative differences in elevation

Leveling Methods

- Most common is direct differential leveling
- Trigonometric leveling
  - observe vertical angle (zenith direction)
  - observe slope distance

- Both used in local surveys

Direct Differential Leveling

- Basic instrument features a telescope and a spirit level tube
  - level tube axis is parallel to line of sight
    - perpendicular to gravity plumb line
- Modern levels are automatic or self-leveling
- Electronic Digital with bar code rod
  - accuracy of 1 mm or less

Direct Differential Leveling

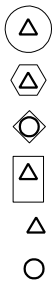
- Procedures
  - method of measuring difference in elevation from a point of known elevation to a point of elevation to be established
    - backsight
    - foresight
    - turning point
    - height of instrument

GGAO Survey Pillar

Control Network

- Primary figure is a triangle
- Braced polygon is most practical and very strong
  - measure all directions (angles) and distances
- Intersection stations not as strong
  - 2 directions minimum, 3 or more is better
- Single line, traverse side shot, is to be avoided

LOCAL CONTROL NETWORK
- GREENBELT (GGAO) -



VLBI ANTENNA

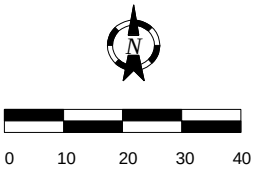
GPS ANTENNA

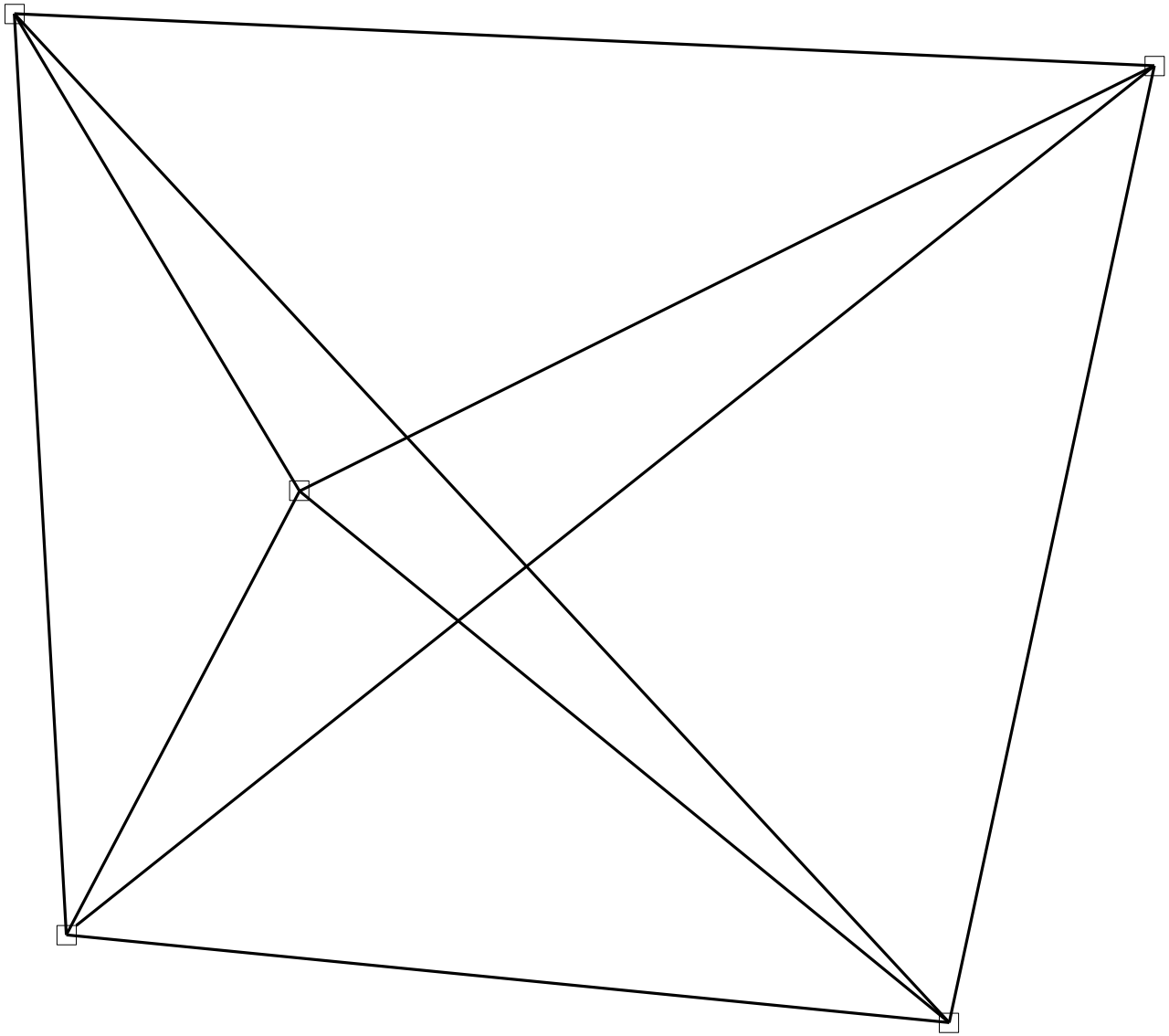
DORIS ANTENNA

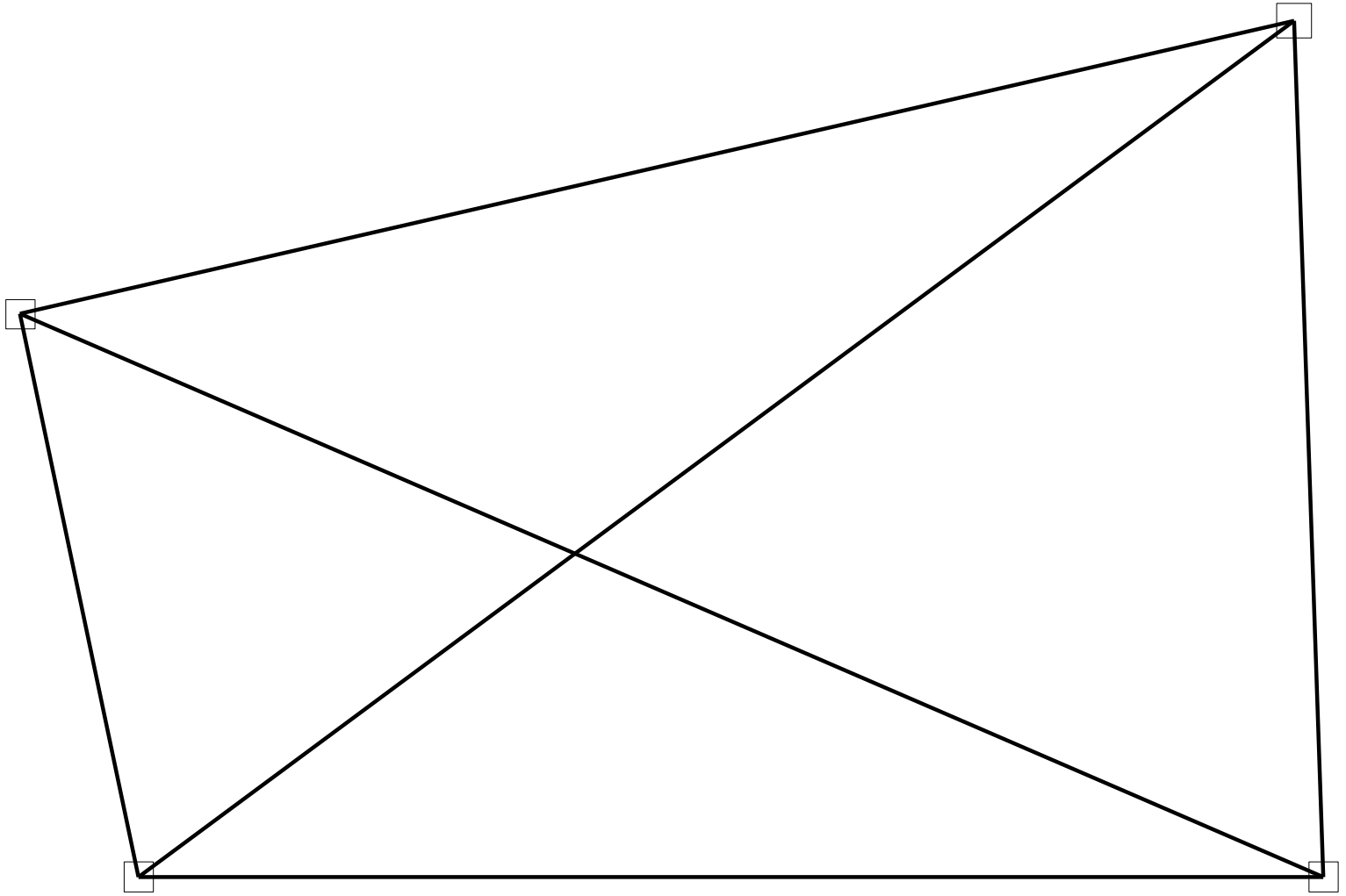
SLR TELESCOPE

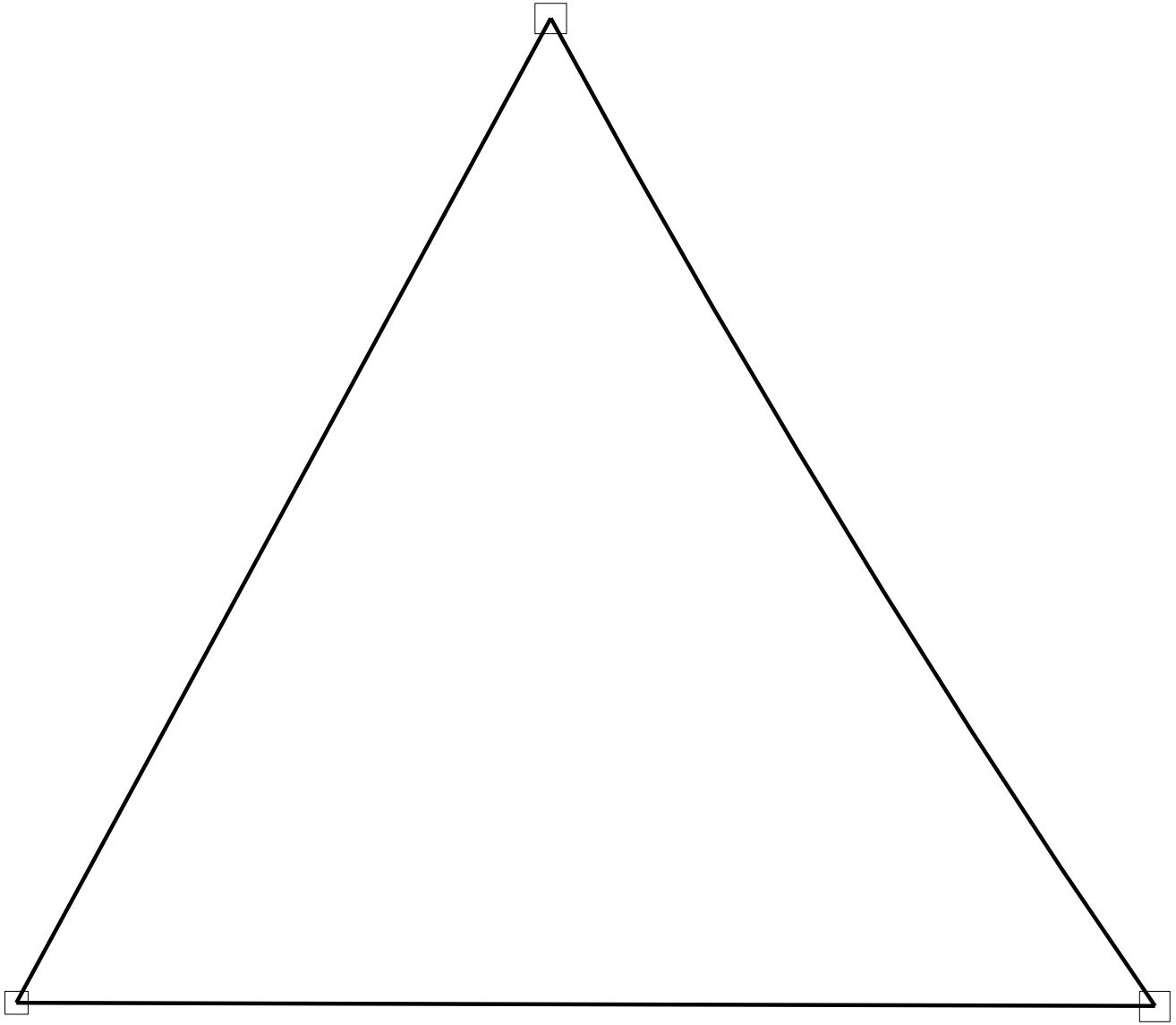
SURVEY MARK

CONCRETE PIER









Survey Instruments at GGAO

Type of Instrument	Manufacturer's Accuracy	Standard Error Used
Leica THEOMAT 3000 (theodolite)	0.5 seconds	1 mm + 1 second
Leica DI 2000 (distancer)	1 mm + 1ppm	1 mm + 1 ppm
Leica NA3003 (digital level)	0.4 mm in 1 Km (with invar rod)	1 mm
Trimble 4000SSE (GPS)	Horizontal: 5 mm + 1 ppm Vertical: 10 mm +1ppm	5 mm + 5 ppm (<1 Km) 5 mm + 1 ppm (> 1 Km)

Background

- The realization of the ITRF is enhanced by the combination of the different space geodetic techniques
- Co-location of the different space geodetic techniques is integral to the ISGN
- The combination and inter- comparison of space geodetic techniques relies on an accurate local tie between the different space geodetic systems
- Requires accuracy of local ties at the 1-2 mm level
  - Close proximity of different systems is beneficial
  - Extended sites make accurate local ties more difficult

System Reference Points

- Compute the location of each axis of rotation
  - Locate targets on the system structure around the axis of rotation
  - Measure to the targets to determine their 3-dimensional coordinates
  - Each axis of rotation determined by separate rotational sequence

Best Practices

- Observe directions, minimum of 4 positions
  - direct and reverse pointing
- Measure distances from both ends of line
  - 2 different instruments, if possible
- Measure vertical distances by direct differential levels to each point
  - double run

Best Practices

- Best monuments are concrete pillars with forced-centering fixtures
  - eliminate plumbing errors
  - improved stability
- Use precise optical plummet for tripod set-ups
  - re-plumb once per day, minimum

Survey Monuments

- Stability most important
  - design for specific geologic characteristics
- Concrete pillar or pier, most often used
  - high strength
  - low coefficient of expansion
- Force-centering fixture to eliminate or minimize centering errors

Motivation

- Z. Altamimi/ITRF has identified local ties at collocation sites to be weakness in ITRF2000
  - missing
  - dubious
- ISGN working on highest priority sites
  - International Space Geodetic Network
  - CSTG Subcommission

Motivation (cont.)

- Ad hoc working group recommendation
  - ILRS: Mike Pearlman, Van Husson
  - GSFC: Chopo Ma
  - ITRF: Zuheir Altamimi

Local Surveys at Greenbelt (poster)

- Local surveys at Greenbelt for
  - SLR Calibration distances
  - Collocation of space geodetic systems
    - SLR, VLBI, GPS, DORIS

Local Surveys at Greenbelt Results

	ΔX [m]	ΔY [m]	ΔZ [m]
7108	75.125	116.762	110.509
7108	75.131	116.767	110.510
residual	+0.006	+0.005	+0.001
7108	75.129	116.765	110.508
residual	+0.004	+0.003	-0.001

	ΔX [m]	ΔY [m]	ΔZ [m]
GODE	54.230	97.009	93.863
GODE	54.235	97.001	93.863
residual	+0.005	-0.008	0.000
GODE	54.235	96.994	93.870
residual	+0.005	-0.015	+0.007

coordinates relative to 7105 itrf97 from network adjustment

coordinates relative to 7105 computed from itrf97
residuals relative to network adjustment

coordinates relative to 7105 computed from itrf2000
residuals relative to network adjustment