# Alignment Network Measurement & Adjustment Software Development at FRIB

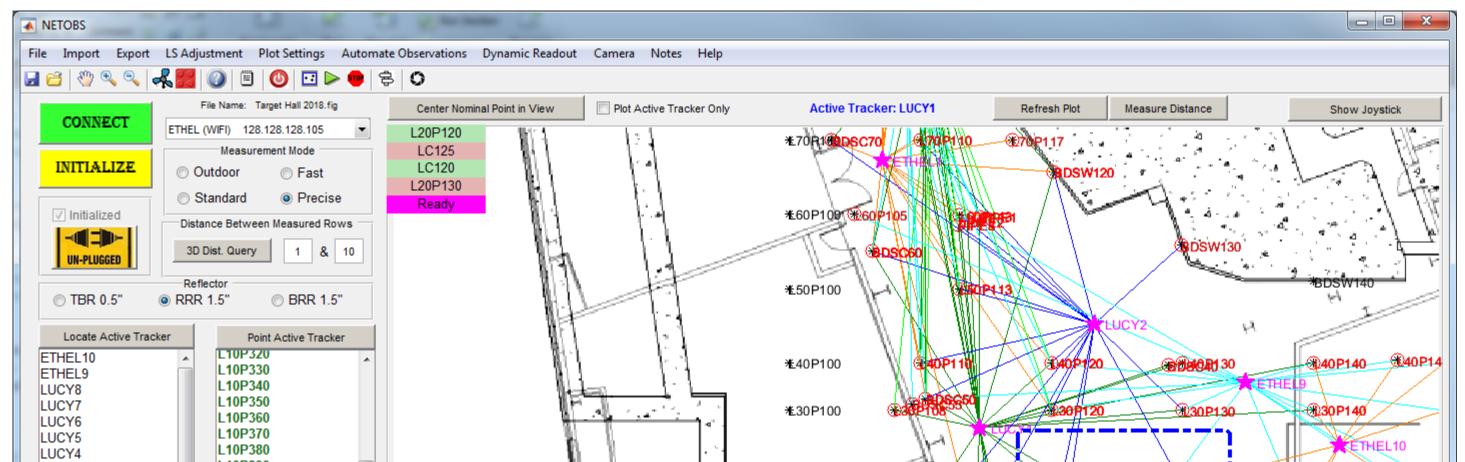
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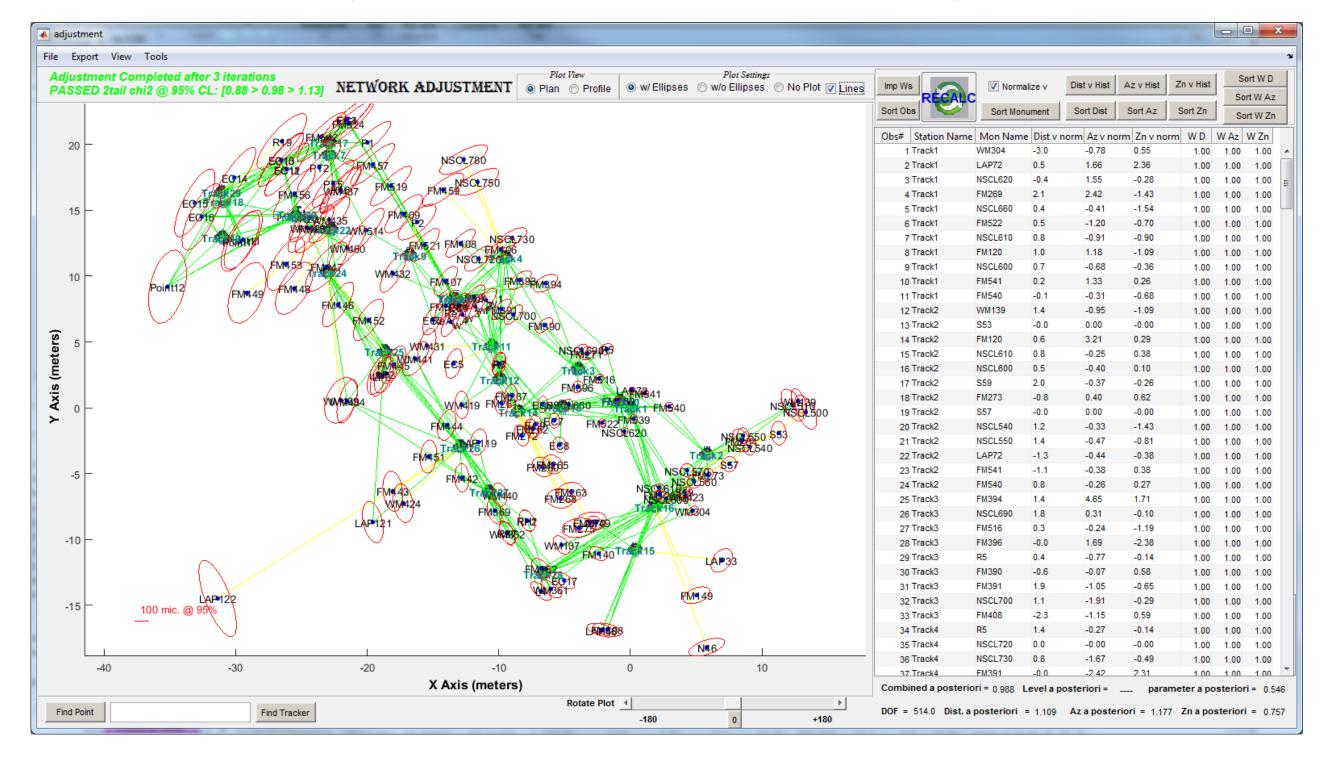
### Abstract

The alignment group at FRIB has developed software to interface with our Leica AT402 laser trackers to take network measurements and perform real-time least squares network adjustment and statistical analysis. The software is named NETOBS (for Network Observation). NETOBS was written in MATLAB\* with the supporting Leica software development toolkit .dll file over the course of several years and compiled to run on any windows computer. NETOBS was written to expedite the time it takes to measure and analyze network measurement data. NETOBS has greatly reduced network measurements, and does least squares adjustment analysis all in one software solution. Using NETOBS improved the network measurement campaign time to less than half that of previous campaigns.

#### **AT402 Interface Module**



## **Network Adjustment & Statistical Analysis Module**



LUCY3 LUCY2 LUCY1 ETHEL8 ETHEL5 ETHEL4 ETHEL3 ETHEL2 ETHEL1 FRED8 FRED7 FRED6	L10P39 L10P40 L10P41 L10P42 L10P43 L17 L20P10 L20P10 L20P10 L20P13 L20P14 <	0 0 0 0 0 0 8 0 0 0	•						₩20P100	BDS(	*20P108 *10P108 220	*****	FP	201P120	<pre>%20P13 %20P13 %20P13 %20P13 %20P130</pre>	H	*20P140 *C140 *LC145	*20P14 H
Tracker Name		Tracker	Point	Azimuth [deg	] Zenith [deg]	Distance [m]	Az σ [sec]	Zen σ [sec	] Dist σ [µm]	t [°C]	p [hPa]	RH [%]	Rot Mag	Time, Mea	as Mode, # of Faces, I	Refl.		
ETHEL10	1	ETHEL10	LC140#	179.56048	78.33963	3.332426	0.07	0.13	0.5	21.20	984.732	51.5	0.3	10-May-20	)18 15:45:46, P, 2F	, R		<u> </u>
Point Name	2	ETHEL10	L30P150	47.69788	109.40072	4.466768	0.27	0.36	0.2	21.20	984.753	51.4	0.3	10-May-20	)18 15:45:01, P, 2F	, R		
LC140#	3	ETHEL10	L20P130	-128.77671	103.59977	6.359208	0.08	0.07	0.1	21.20	984.717	51.4	0.3	10-May-20	)18 15:44:13, P, 2F	, R		
	4	ETHEL10	L20P140	-171.92059	128.94598	2.372816	0.26	0.19	0.3	21.20	984.792	51.0	0.2	10-May-20	18 15:43:28, P, 2F	, R		
MEASURE	5	ETHEL10	L20P147	99.51670	118.83001	3.079678	0.39	0.57	0.5	21.20	984.741	50.6	0.2	10-May-20	)18 15:42:16, P, 2F	, R		
	6	ETHEL10	L30P140	-60.33049	131.92991	2.227119	0.28	0.16	0.2	21.30	984.762	50.6	0.2	10-May-20	)18 15:41:16, P, 2F	, R		
2 Face Measurement	7	ETHEL10	L40P140	-41.37046	114.32329	3.608263	0.30	0.25	0.1	21.30	984.795	50.9	0.3	-	)18 15:40:38, P, 2F			
	8	ETHEL10		27.80234	106.18649	5.295300	0.45	0.18	0.2	21.40	984.685	51.0	0.3	-	)18 15:39:22, P, 2F			
Find SMR Locate SMR	9	ETHEL10		10.09973	110.66223	4.171817	0.50	0.07	0.6	21.40	984.691	51.1	0.3	-	)18 15:38:32, P, 2F			
Delistas Devis	10	ETHEL10		179.56039	78.33965	3.332426	0.09	0.12	0.6	21.40	984.639	51.4	0.3		)18 15:37:41, P, 2F			
Point to Row 9	11	ETHEL9	BDSC40#	55.40877	77.81467	3.100349	0.24	0.30	0.3	21.20	984.660	51.4	0.5	-	)18 15:33:35, P, 2F			
	12	ETHEL9	L20P147	-103.52871	102.09044		0.14	0.22	0.3	21.20		51.5	0.5	-	18 15:31:26, P, 2F			
Delete Row(s) 406	12	-	L 60P105	66 06163		16 302618	0.14	0.22	0.3	21.20	984 570	51.8	0.5	-	18 15:30:22 P 2F	-		-

- Complete control of AT402 through Ethernet or Wi-Fi
  - Measurements in Precise, Outdoor, Standard, and Fast modes
  - Real-time monitoring and display of AT402 status: Locked on SMR, levelness, plugged in, and initialized
  - Display AT402 overhead view camera live color video and capture and save video image
  - Drive AT402 head with overhead view camera NETOBS display or NETOBS joystick
  - Real-time AT402 watch window  $\Delta X$ ,  $\Delta Y$ ,  $\Delta Z$  read-out for component alignment or coordinate layout
  - Smart AT402 search for SMR
  - Power off AT402
- Automatic measurements
  - Drives AT402 to measure multiple monuments automatically within a user-drawn perimeter (with an optional left-click-to-continue / right-click-to-retry-previous-measurement pause between measurements)
  - Automatically names monument measurements by nearest neighbor to nominal within user tolerance

#### Dynamic plotting

 Display settings include the optional plotting of tracker positions, nominal network points, measurement lines, measured points, point names, and the FRIB building outline

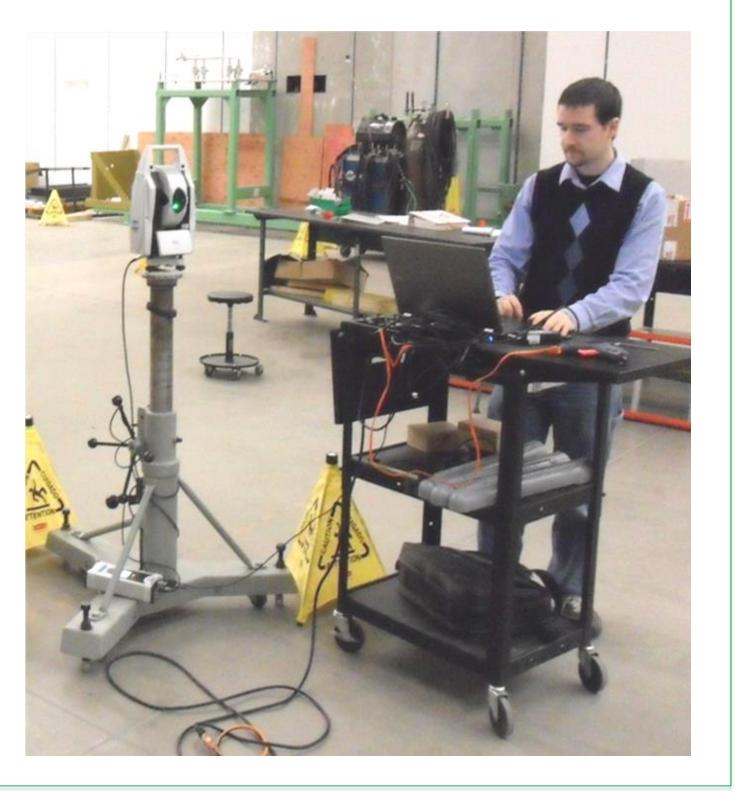
- Least squares network adjustment
  - Least squares adjustment of network measurement data can be done quickly in the field on all or a subset of the network measurements. Periodically checking the statistical adjustment of the network in the field can test the quality of measurements and allow environmental or procedural factors to be addressed sooner. Leveling data can be included in the network adjustment.
- Statistical analysis
  - Plot normalized measurement residual distributions for azimuth, zenith, and distances
  - Chi Squared tests for total network adjustment and for each measurement type
- Blunder detection
  - Sort a posteriori adjusted measurements by magnitude of normalized residuals to identify outliers
- Flexible datum definition options (A and B do not require a priori monument coordinates)
  - A: Constrain first tracker position to X = 0, Y = 0, Z = 0, Rx = 0, Ry = 0, Rz = 0
  - B: Inner network constraints
  - C: Weighted datum point constraints
- Flexible stochastic modeling
  - Set a priori standard deviations for each measurement type
    - » Azimuths
    - » Zeniths
    - » Distances
  - » Tracker Levelness
  - » Leveling data
- Gravity Modeling
  - Uses localized sphere model

Norm	alized	distance	e residual	distrib	ution	plot
	Figure 1				×	

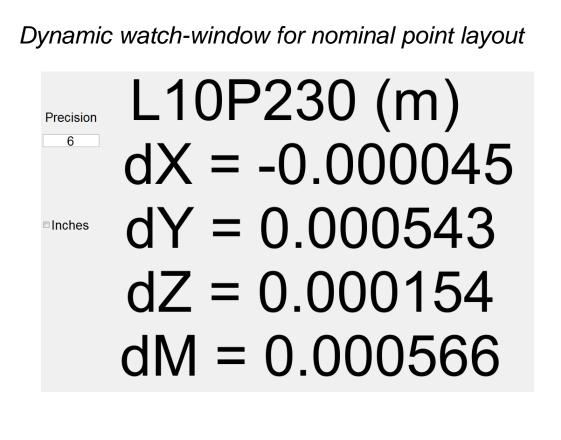
adju	Adjustment settings									
File	Export View	Tools								
X		teration Termination Max # of Iterations Valstop = 0.1 Set First Tracke Inner Constrain Weighted Contr	s = 10 00001 er: Rx=0, R nts	♥ Scale s <b>Define [</b> y=0, Rz=0, Tx=	Datum	stRefVar if fail C	hiSqr test			Observation Weights Stochastic Model Az $\sigma = \begin{bmatrix} 8 & \mu m + 3 & ppm \end{bmatrix} \div sin(zn)$ Zn $\sigma = \begin{bmatrix} 8 & \mu m + 3 & ppm \end{bmatrix}$ Rx & Ry lev $\sigma = \begin{bmatrix} 0.5 & sec. \end{bmatrix}$
			roi							,
	Monument	fix pnt. (fix = 1)	Х	Y	Z	std X (m)	std Y (m)	std Z (m)		Dist $\sigma = 8 \mu m + 1 ppm$ Min D $\sigma = 20 \mu m$
1	Monument EC1		Х	Y	Z	std X (m)	std Y (m)	std Z (m)	*	
-			Х	Y	Z	std X (m)	std Y (m)	std Z (m)	*	Dist $\sigma = 8 \mu m + 1 ppm$ Min D $\sigma = 20 \mu m$ All Trackers Level
2	EC1 EC10 EC11		Х	Y	Z	std X (m)	std Y (m)	std Z (m)	*	☑ All Trackers Level
2 3 4	EC1 EC10 EC11 EC12		Х	Y	Z	std X (m)	std Y (m)	std Z (m)	*	Image: State
2 3 4 5	EC1 EC10 EC11 EC12 EC13		X	Y	Z	std X (m)	std Y (m)	std Z (m)	-	Image: State Sta
2 3 4 5 6	EC1 EC10 EC11 EC12 EC13 EC14		X	Y	Z	std X (m)	std Y (m)	std Z (m)	*	Image: State Stat
2 3 4 5 6 7	EC1 EC10 EC11 EC12 EC13 EC14 EC15		X	Y	Z	std X (m)	std Y (m)	std Z (m)	*	Image: Second state
2 3 4 5 6 7 8	EC1 EC10 EC11 EC12 EC13 EC14 EC15 EC16		X	Y	Z	std X (m)	std Y (m)	std Z (m)	*	Image: State
2 3 4 5 6 7 8 9	EC1 EC10 EC11 EC12 EC13 EC14 EC15 EC16 EC17		X	Y	Z	std X (m)	std Y (m)	std Z (m)		Image: Second state     Image: Second state       Image: Second state     Image: Second state       Image: Second state     Image: Second state       Image: Image: Second state     Image: Second state       Image: Image: Image: Second state     Image: Second state       Image: Image: Image: Image: Image: Second state     Image: Second state       Image: Ima
2 3 4 5 6 7 8 9 10	EC1 EC10 EC11 EC12 EC13 EC14 EC15 EC16 EC17 EC2		X	Y	Z	std X (m)	std Y (m)	std Z (m)		Image: Second state     Image: Second state       Imag
2 3 4 5 6 7 8 9 10 11	EC1 EC10 EC11 EC12 EC13 EC14 EC15 EC16 EC17		X	Y	Z	std X (m)	std Y (m)	std Z (m)		Image: Second state     Image: Second state       Image: Second state     Image: Second state       Image: Image: Second state     Image: Second state       Image: Image: Image: Second state     Image: Second state       Image: Image: Image: Image: Image: Second state     Image: Second state       Image:

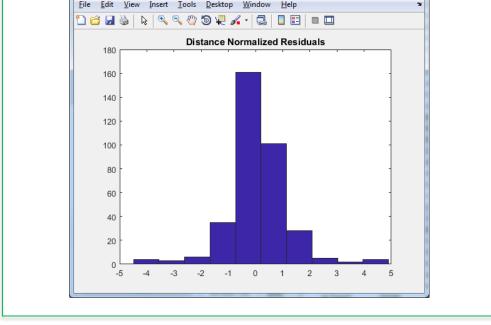
- Locate AT402 (after minimally measuring 3 network monuments)
  - Interactive least squares best fit transformation routine with the option to fit to a nominal list of network
    points or measurements from a previous tracker position
- Records standard deviation of measured angles and distances
  - Measurement lines with standard deviations above 3 sigma are highlighted in red
- Possible future additions to NETOBS
  - Add more instruments that can interface with NETOBS
  - Record the difference between the backsite and foresite of a 2 face measurement and give a warning if the difference is greater than a user defined tolerance
  - Add magnet mapping equipment interface to work simultaneously with laser tracker measurements
  - Add beamline component as-aligned calculations
  - Add geometric fitting to measurements

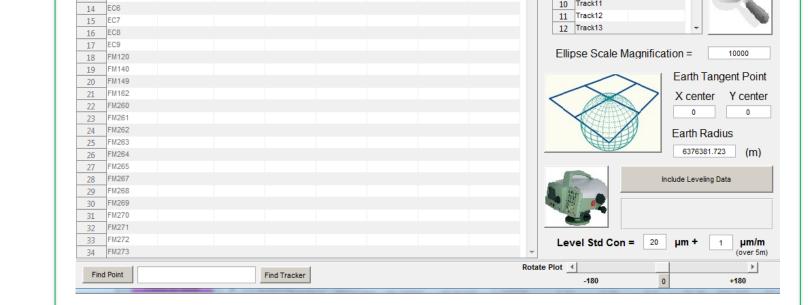
Taking monument network campaign measurements with an AT402 controlled by NETOBS software



Least squares	best fit a	transformation to locate AT402
		Recalculate
Contstrian the Scale to Equal 1.000	include in calc.	UHCW18 dX = 0.000208 dY = 0.000047 dZ = 0.000064 dMag = 0.000223
Rotation Matrix	vinclude in calc.	TPORT5 dX = 0.000063 dY = 0.000022 dZ = 0.000011 dMag = 0.000068
	V include in calc.	TPORT9 dX = -0.000031 dY = -0.000011 dZ = 0.000013 dMag = 0.000035
0.299030 -0.954244 -0.000017	vinclude in calc.	TPORT4 dX = 0.000031 dY = 0.000012 dZ = -0.000000 dMag = 0.000033
0.954244 0.299030 0.000074	☑ include in calc.	TPORT10 dX = -0.000026 dY = -0.000009 dZ = -0.000008 dMag = 0.000029
-0.000065 -0.000039 1.000000	vinclude in calc.	TPORT7 dX = -0.000024 dY = -0.000013 dZ = -0.000001 dMag = 0.000027
	vinclude in calc.	TPORT6 dX = -0.000014 dY = -0.000000 dZ = -0.000014 dMag = 0.000019
scale = 1.000000		
tx = 210.319156 ty = 455.557955 tz = 45.305793		







#### \* MATLAB and Statistics Toolbox Release 2014b, The MathWorks, Inc., Natick, Massachusetts, United States.



# **Facility for Rare Isotope Beams**

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