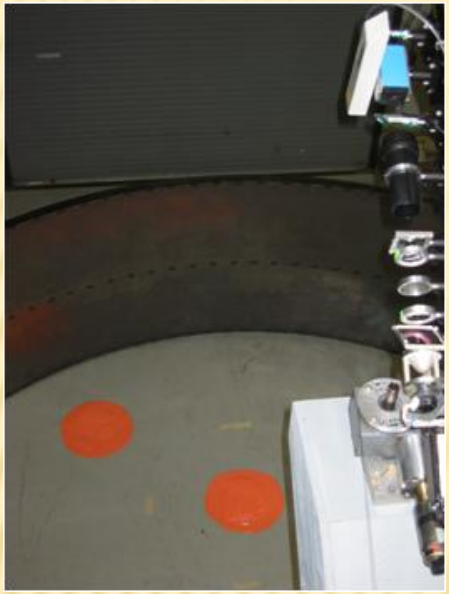
In-tank/At-tank Characterization for Closure of Hanford Tanks



Ping-Rey Jang, Zhiling Long,
O. Perry Norton, Walter P. Okhuysen,
and David L. Monts
Institute for Clean Energy Technology
(ICET)
Mississippi State University
November 18, 2010

Print

Close

Agenda

- Need for Fourier Transform Profilometry (FTP)
- Overview of FTP Technique
- Current Status
  - FTP with Synthetic Reference Images
  - Improved Camera Stability
  - Effect of Ambient Light on Volume Determination
  - Demonstration of FTP Prototype System at ICET
- Path Forward

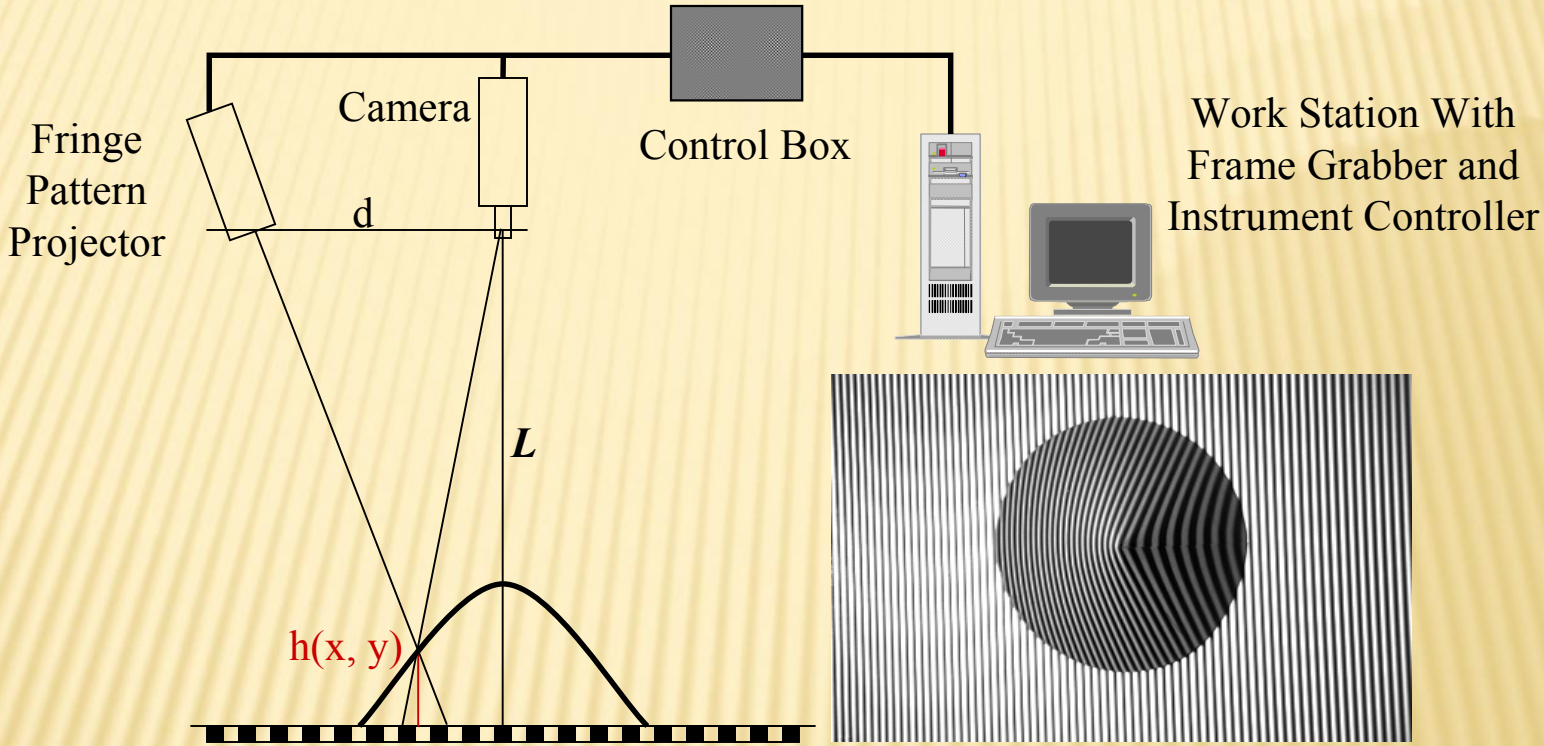
Print Close

Bottom of Hanford Tank C-106

CH2MHILL
Hanford Group, Inc.

Improved tools for residual waste volume determination are expected to provide site operators and regulators with verifiable information that can be used in determination of closure timelines.

Principle of the FTP Technology

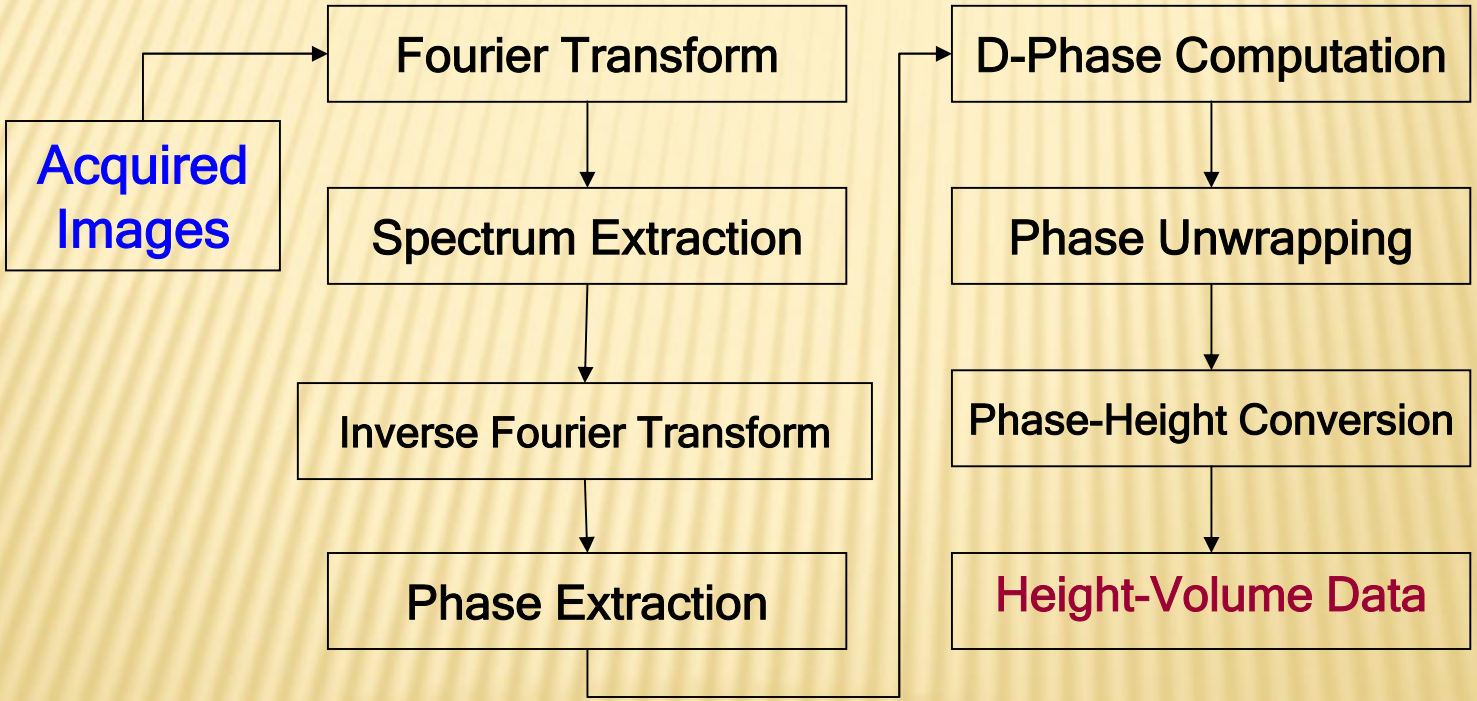


$$h(x, y) = \frac{L\Delta\Phi(x, y)}{\Delta\Phi(x, y) - 2\pi f_0 d}$$

Where:
h = height
$\Delta\Phi$ = phase variation
f_0 = fundamental frequency

FTP Process Flow Chart

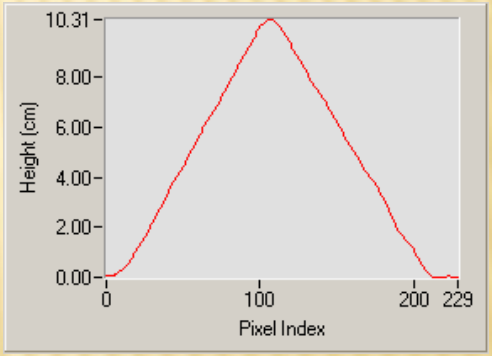
Fourier Transform Profilometry (FTP) - A 3-D shape measurement technique. Projecting a fringe pattern upon target surface and observing its deformation from a different view angle.



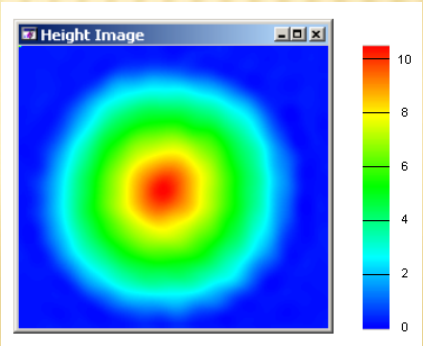
Typical Measurement Results under Simulated Conditions

- Distance between camera and target: 4.55 m
- Distance between camera and projector: 21.0 cm
- Ronchi filter: 9.84 lines/mm
- Target: paper cone with base diameter Φ = 26.7 cm and peak height = 10.4 cm

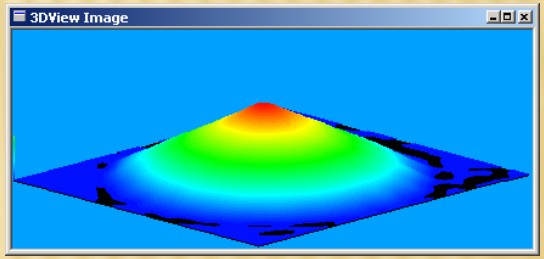
Target



Reconstructed 1D Profile



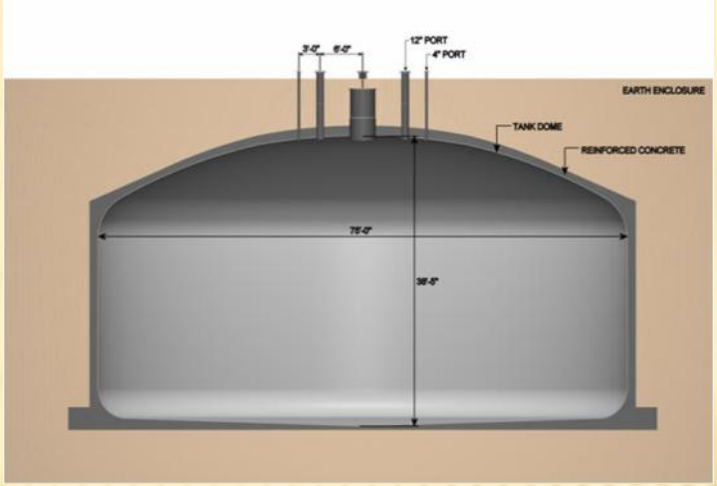
Reconstructed 2D Profile



Reconstructed 3D Profile

	Target	Measured	Error
Peak Height (cm)	10.4	10.31	0.9%
Volume (cm^3)	1941.00	1962.73	1.1%

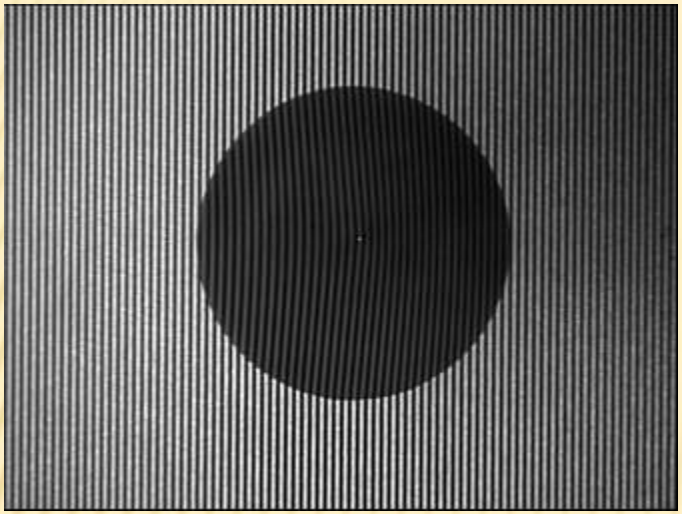
Deployment Design Criteria



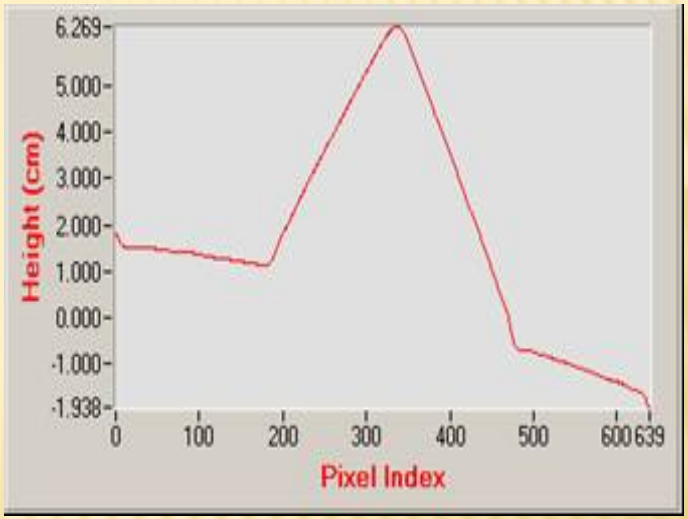
Design Goals for In-Tank FTP Probe Inspection System

- Must be deployable through 10-cm ID riser.
- Insertion depths of 2.7 to 9 m.
- Ability to pan 360 º and to tilt 120°.
- Illumination must be provided.
- Deployment by 2 technicians wearing protective garment & heavy gloves w/o use of “crane.”
- Max. riser loads of 2200 N axial & 340 N-m bending moment.
- Operator lifting limitation of 18 kg will require breakdown into subassemblies.

FTP Determinations with Synthetic Reference Images



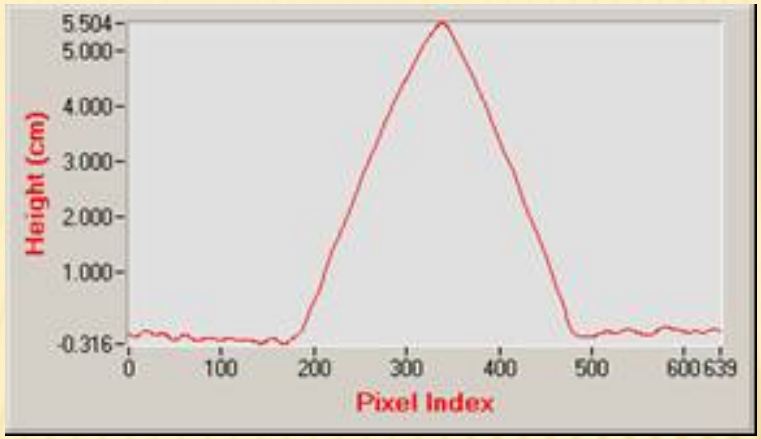
FTP Image with Target



1-D Reconstruction of First Result Using Synthetic Reference Image

In effect, FTP determines volumes by comparing an image without the target ("reference image") from an image with the target. For volume determination within Hanford waste tanks, it will be necessary to computationally generate the reference images using "as-built" drawings.

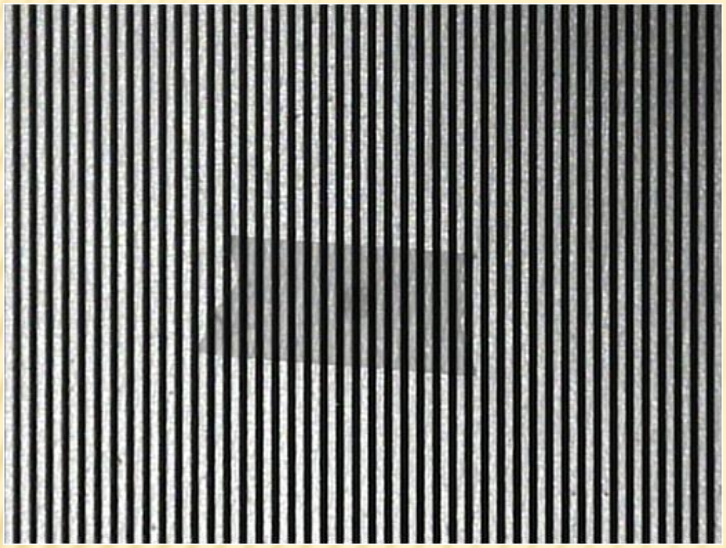
FTP Determinations with Synthetic Reference Images



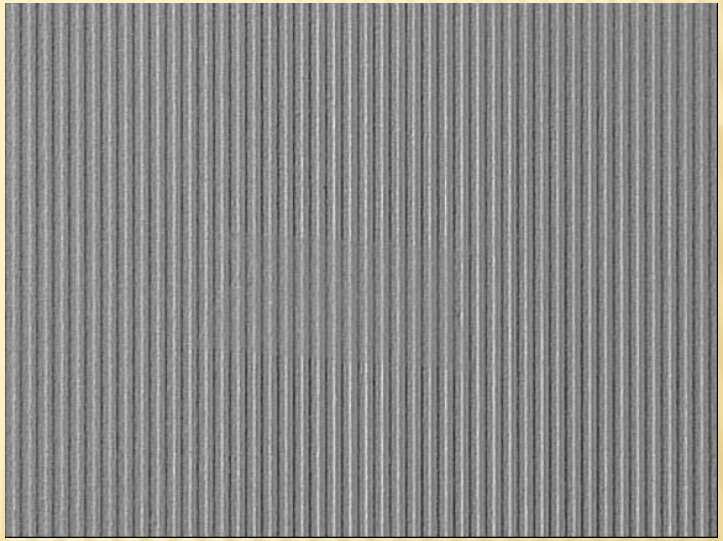
1-D Reconstruction Using Synthetic Image with Correct Tilt of Fringe Lines and Camera Lens Distortion Correction

Reference Image	Truth Volume (cm^3)	FTP Volume (cm^3)	Error (%)
Real Reference	265.5	256.0	-3.6
Synthetic Reference with Correction	265.5	254.7	-4.1

Investigation of Camera Stability
Time-Dependent Fringe Pattern Change



Fringe pattern (image # 1)



Result obtained by subtracting image # 1 from image # 10. If no change, this would be all black.

Images automatically recorded at 5 minute intervals.

Cause of Intensity Instability

We have determined that the intensity fluctuations with the SONY block cameras at thermal equilibrium (i.e., even after warm-up) are associated with the analog-to-digital (A/D) conversion process. The digital image acquired by the SONY block camera is converted to an analog signal for transmission to the image acquisition computer, where the image is converted from analog format back to digital format for storage. For the SONY color camera, this leads to about a 4% variation in intensity.

Improved Camera Stability

Cameras using FireWire (IEEE 1394) transmission transfer the image directly in digital format. We have found that multi-hour tests indicate that The Imaging Source DMK 31BF03-Z2 progressive scan FireWire camera produces no change in pixel intensity (i.e., zero intensity fluctuation) and has no warm-up time.

FTP Volume Determinations Comparison

Camera	Target	Measured Volume (cm^3)	True Volume (cm^3)	Absolute Error (cm^3)	Relative Error (%)
FireWire	Cone 1	272.5 ± 1.0	265.5	7.0	2.6
Sony 78B	Cone 1	253.3 ± 1.6	265.5	-12.2	-4.6
FireWire	Cone 2	464.0 ± 1.8	450.4	13.6	3.0
Sony 78B	Cone 2	449.9 ± 3.5	450.4	-0.5	-0.1
FireWire	Cone 3	155.3 ± 1.1	158.3	-3.0	-1.9
Sony 78B	Cone 3	159.7 ± 2.1	146.8	-11.5	-7.3

Average FireWire camera relative error 1.3%
Average Sony 78B camera relative error -4.0%

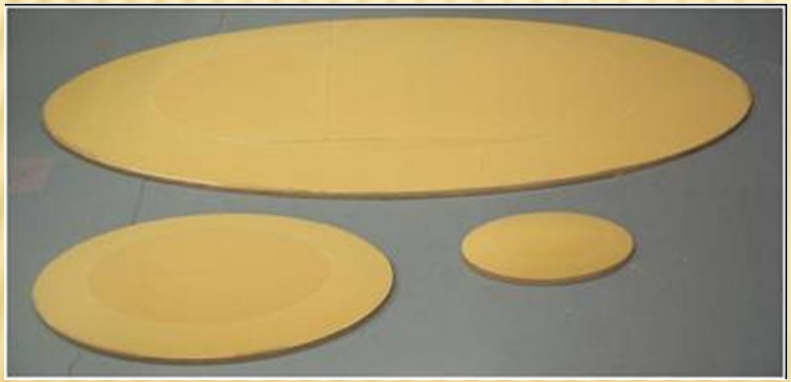
Print Close

Effect of Ambient Light Level on FTP Volume Error

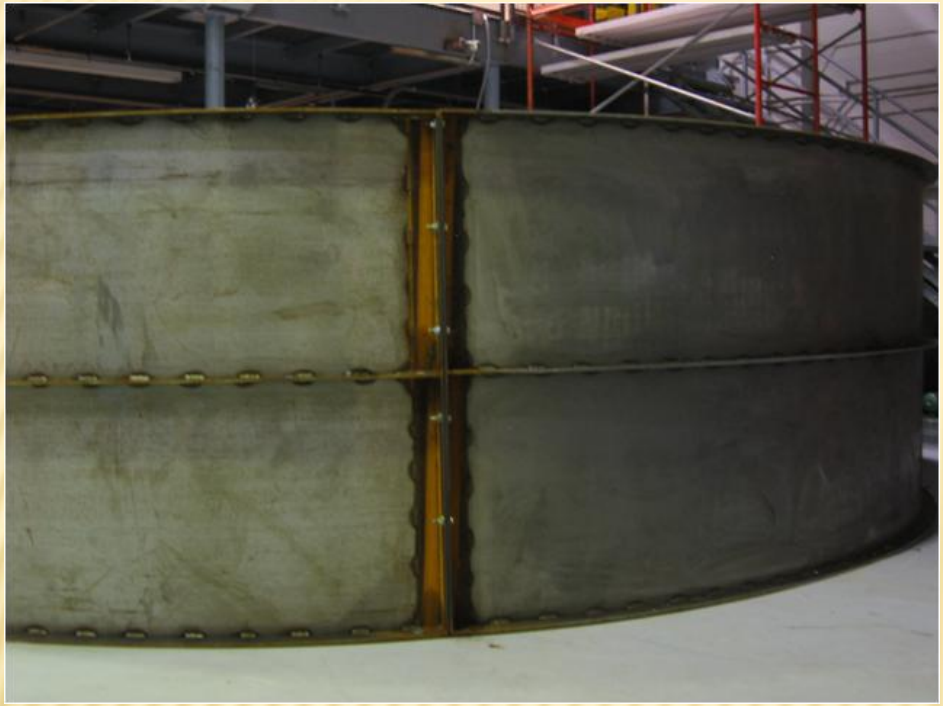
Scene Light Level (EV)	Relative Volume Error (%)	Reconstruction Quality
5.8	2.0	Good
5.9	2.9	Good
6.1	3.4	Good
6.1	3.4	Good
6.3	4.0	Good
6.9	3.2	Good
7.5	5.0	Good
8.1	3.1	Fair
8.7	5.0	Bad
9.3	6.4	Bad
9.9	5.3	Bad

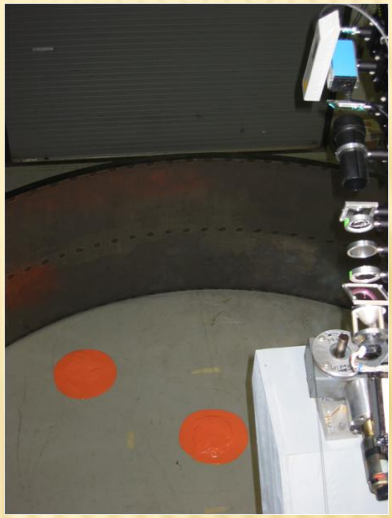
Exposure value (EV) combines effect of camera shutter speed and aperture (*f* -number): EV equals base-2 logarithm of square of *f*-number divided by exposure time.

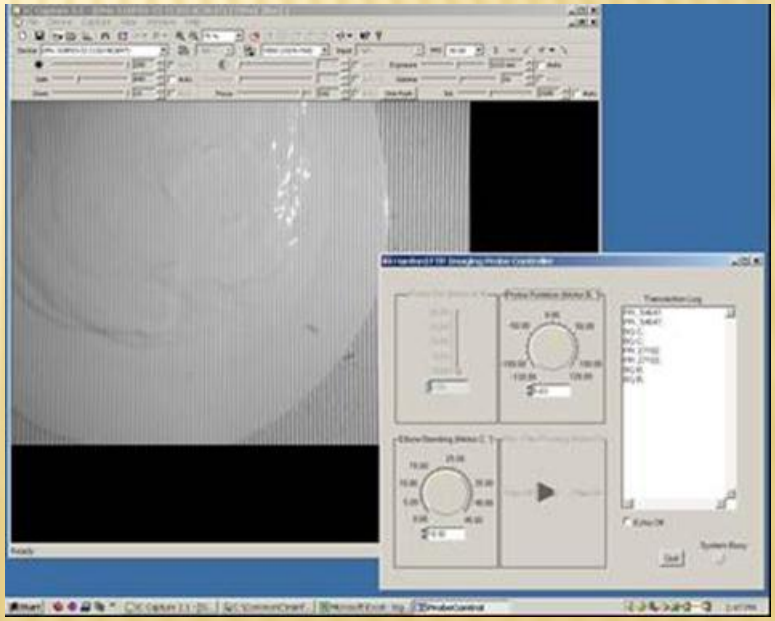
Development of Prototype System



FTP Demonstration in ICET Highbay





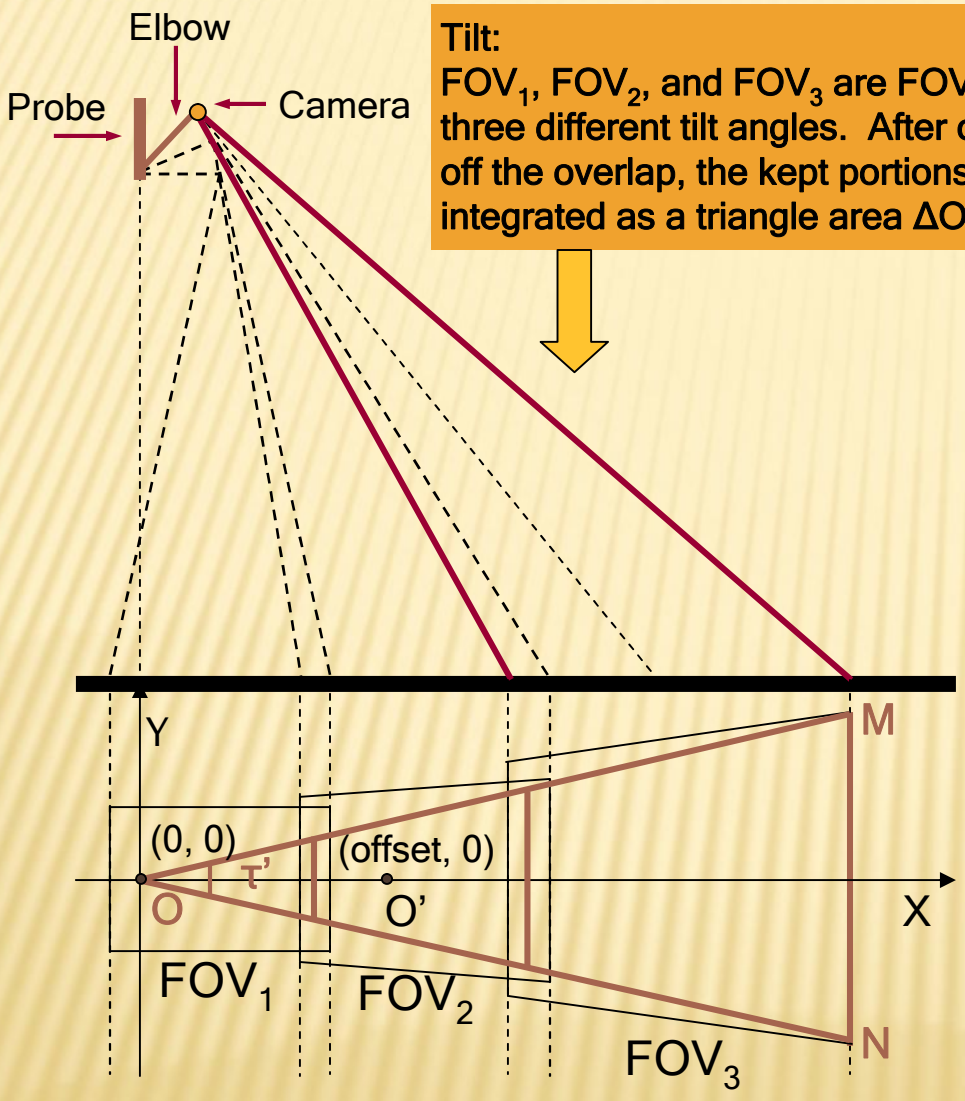


FTP Demonstration Results

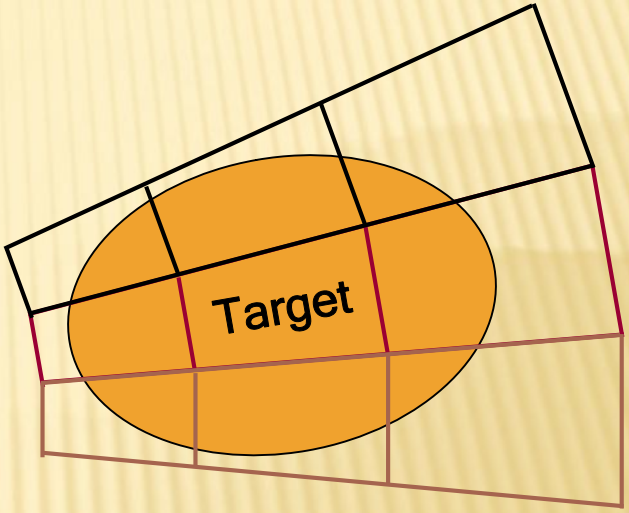
Target	FTP Volume (cm^3)	True Volume (cm^3)	Average Error (cm^3)	Average Error (%)
S3	2007 ± 39	1954 ± 10	53	2.7%
S4	1087 ± 16	1071 ± 6	16	1.5%
S5	425 ± 23	422 ± 5	3	0.7%
S6	672 ± 26	647 ± 4	25	3.9%
Average				2.2%

Five FTP replicate determinations each of nondescript targets in single images

Multiple Images Integration ("Stitching")



Tilt:
FOV_1, FOV_2, and FOV_3 are FOV's at three different tilt angles. After cutting off the overlap, the kept portions are integrated as a triangle area ΔOMN.



- Images are acquired at different tilt and rotation angles, with overlap between the adjacent ones.
- For height profiles generated from each image, the overlap is cut off.
- The kept portions are added together to obtain the overall volume result for the whole tank floor.

“Blind” FTP Stitching Results

Target	FTP Volume (cm^3)	True Volume (cm^3)	Error (cm^3)	Error (%)
OPN#1	1955	2190 ± 13	-235	-10.8%
OPN#1	2006	2190 ± 13	-184	-8.4%
OPN#1	1932	2190 ± 13	-258	-11.8%
OPN#4	1742	1785 ± 13	-43	-2.4%
OPN#4	1725	1785 ± 13	-60	-3.4%
OPN#4	1983	1785 ± 13	198	11.1%

Each FTP volume determined by stitching six images together.
Uncertainty of true volume is 95% confidence limit.

Path Forward

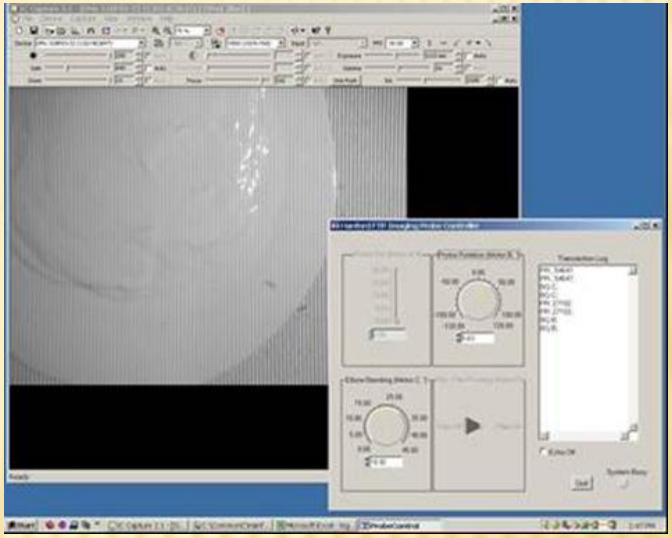
- Completion of demonstration of prototype FTP system at ICET
- Technology transfer

Acknowledgments

We wish to thank Sharon Marra and Jeff Griffin of SRNL for their encouragement.

This effort was funded by the U.S. Department of Energy's Office of Environmental Management through Cooperative Agreement DE-FC01-06EW-07040.

Questions ?



Contact Information:

Dr. David L. Monts
Institute for Clean Energy Technology (ICET)
Mississippi State University
Phone: (662) 325-7389
E-mail: Monts@ICET.MsState.Edu

Print
Close