



3D Thermal Scanning for Refractory Risk Management of Glass Furnaces

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Title: Founder of Plume Digital



Introduction To The Speaker And The Company

Corey Forster

Founder of Plume Digital

Formerly, PaneraTech

Formerly, HarbisonWalker International
Operations experience in foundries and
steelmaking

Degrees in Physics & Mech Engineering



Introduction To The Speaker And The Company

PLUME DIGITAL's mission is to help clients collect and analyze thermal datasets to reduce risk, inform maintenance cycles, and extend asset campaigns.



The work presented here includes patent-pending methods and systems.

Special Thanks To Libbey Glass



LIBBEY®

Refractory Condition And Its Economic Value

Furnaces are major capital assets.

Their campaign life has an inherent and calculable economic value.

Early refractory degradation may have multiple remediation options.

If deterioration is identified early enough, operators may have options:

- engineered cooling
- overcoats / ceramic welding / hot repair
- planned maintenance or rebuild preparation

Time is itself valuable.

Earlier detection means more remediation options, better material / personnel planning, and potentially additional campaign life.



So Why Use Temperature Measurements?

Mature measurement technology

Thermocouples, pyrometers and thermography are established industrial technologies.

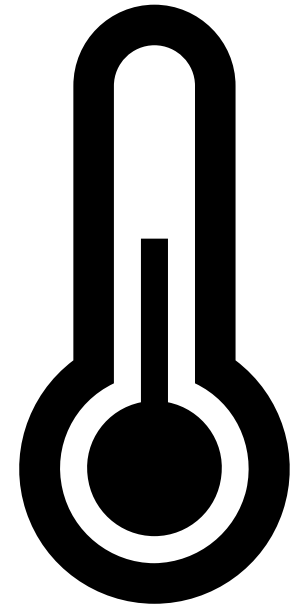
Economical and scalable sensing

Temperature measurement can be comparatively economical relative to many other NDT approaches and can be acquired with commercial off-the-shelf equipment.

Useful refractory information

Temperature can support:

- anomaly detection
- trending of changing conditions
- inference/estimation of residual refractory thickness when coupled with an appropriate thermal model



The Challenge Isn't Temperature Measurement, It's Data Quality

SCALABILITY OF COVERAGE

Do we inspect enough of the containment envelope to find a potential problem?

CONTINUITY OF DATA

Do we measure often enough to distinguish change from noise?

SOLUTION COST

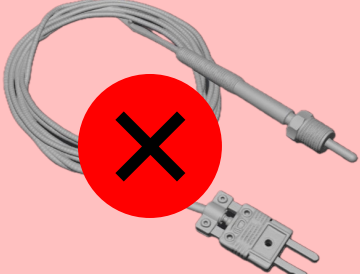
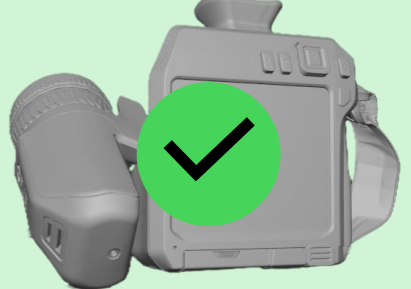
What does it cost to achieve sufficient coverage and continuity?

EASE OF ALGORITHMIC COMPARABILITY

Can a measurement from today's inspection be compared with a prior measurement at the same location?



How To Evaluate Various Temperature Measurement Tech?

	FIXED	MOBILE
SINGLE POINT	 THERMOCOUPLE	 PYROMETER GUN
POINT ARRAY	 FIXED IR CAM	 HANDHELD IR CAM

SCALABILITY OF COVERAGE

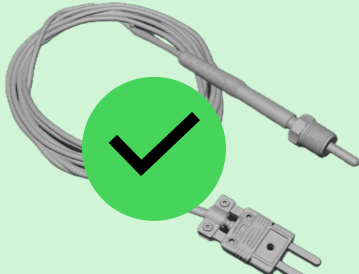
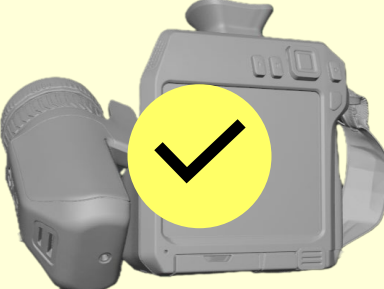
Evaluate spatial coverage within a single inspection instance

Single-point solutions are impractical for complete coverage.

Fixed solutions require many installations to achieve complete coverage.



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CONTINUITY OF DATA

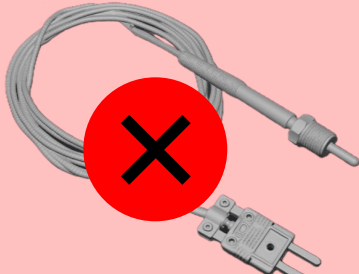
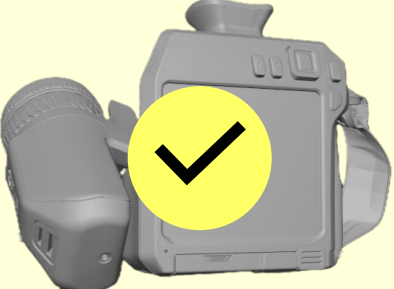
Cadence of data collection or number of time series instances

Fixed solutions can provide continuous or high-frequency time-series data

Mobile solutions can sufficiently provide continuity IF used frequently



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SOLUTION COST

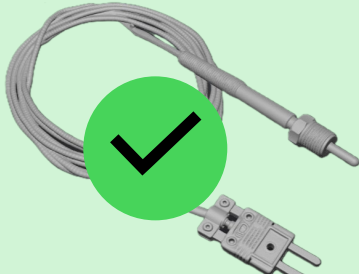
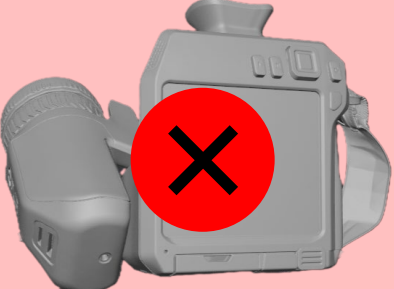
Consider total solution CAPEX plus ongoing OPEX for data capture.

Solution needs to be capable of large amount of data across a large area.

Cost Per Useful Data Point is relevant; redundant high-frequency measurements should not dominate the comparison.



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EASE OF ALGORITHMIC COMPARABILITY

MOST IMPORTANT CRITERION

Can one temperature measurement be easily compared to another at a given location?

Can similar locations be compared to each other?



What If Every Temperature Measurement Had a Coordinate?

This is the question that led to the current iteration of my project and its many prototypes, a project I call...

3DEGREE

The challenge became converting unstructured thermographic imagery into a structured spatial dataset.



From Thermography to 3D Temperature Models

The '3DEGREE' Scanner

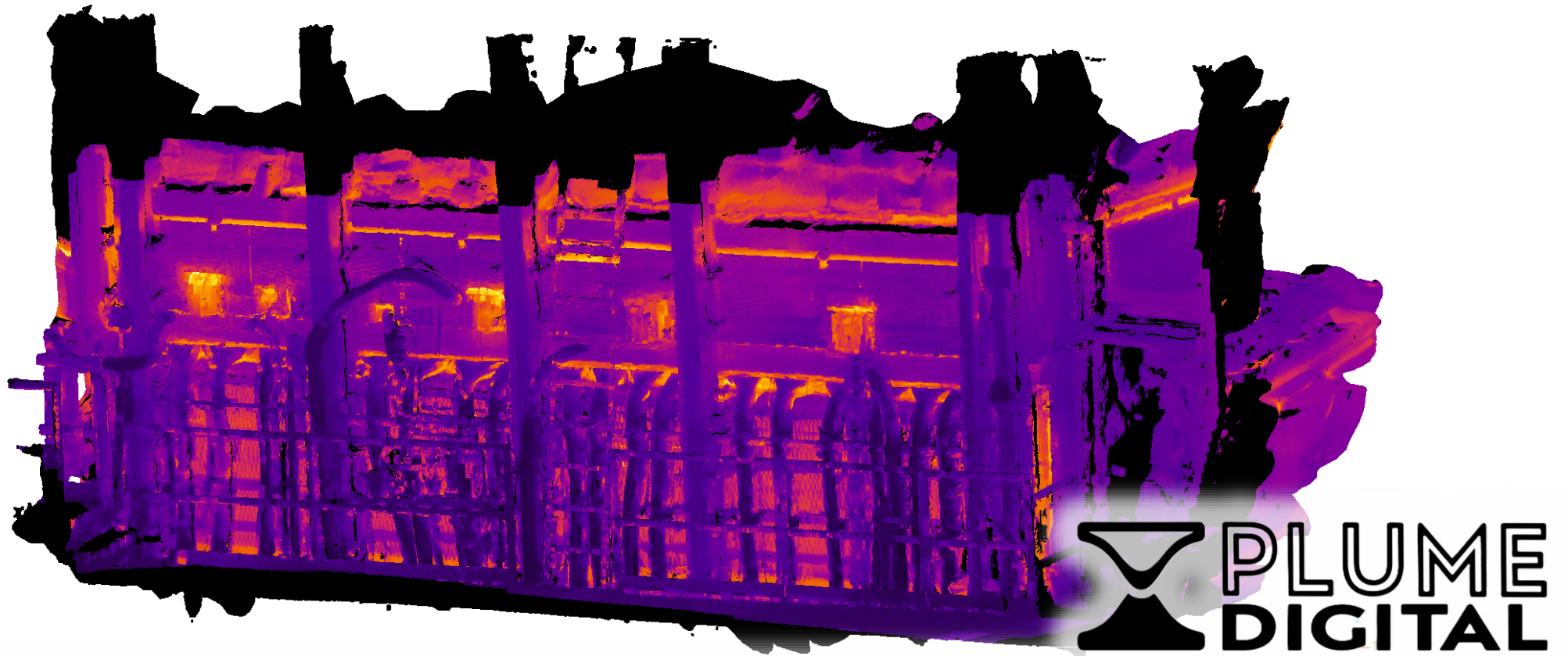
- Data fusion of localization, spatial sensing, and temperature sensing capabilities
- Data pipeline to generate point cloud, mesh, and/or 3DGS
- Tens to hundreds of millions of temperature measurements
- Inspection speeds exceeding 5000 ft²/hr of field inspection



3DEGREE – Visual Furnace Reconstruction



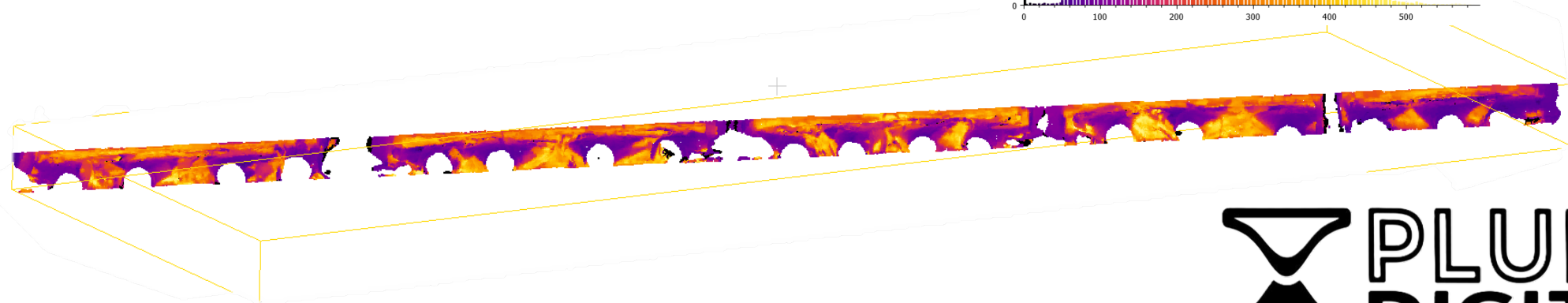
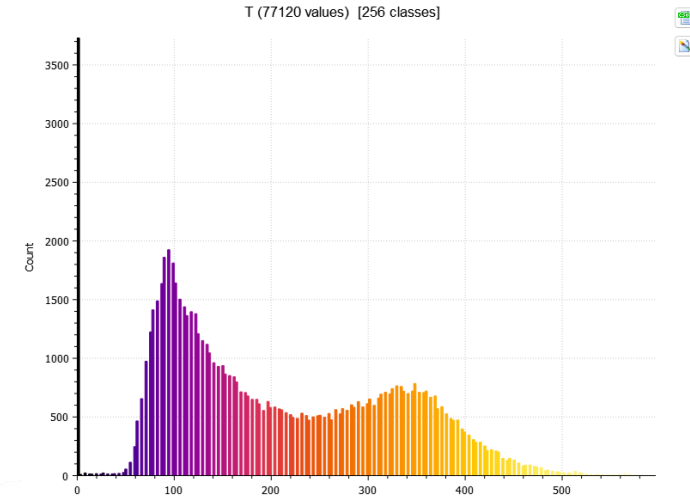
3DEGREE – Thermal Furnace Reconstruction



3DEGREE – Voxel Segmentation and Analysis

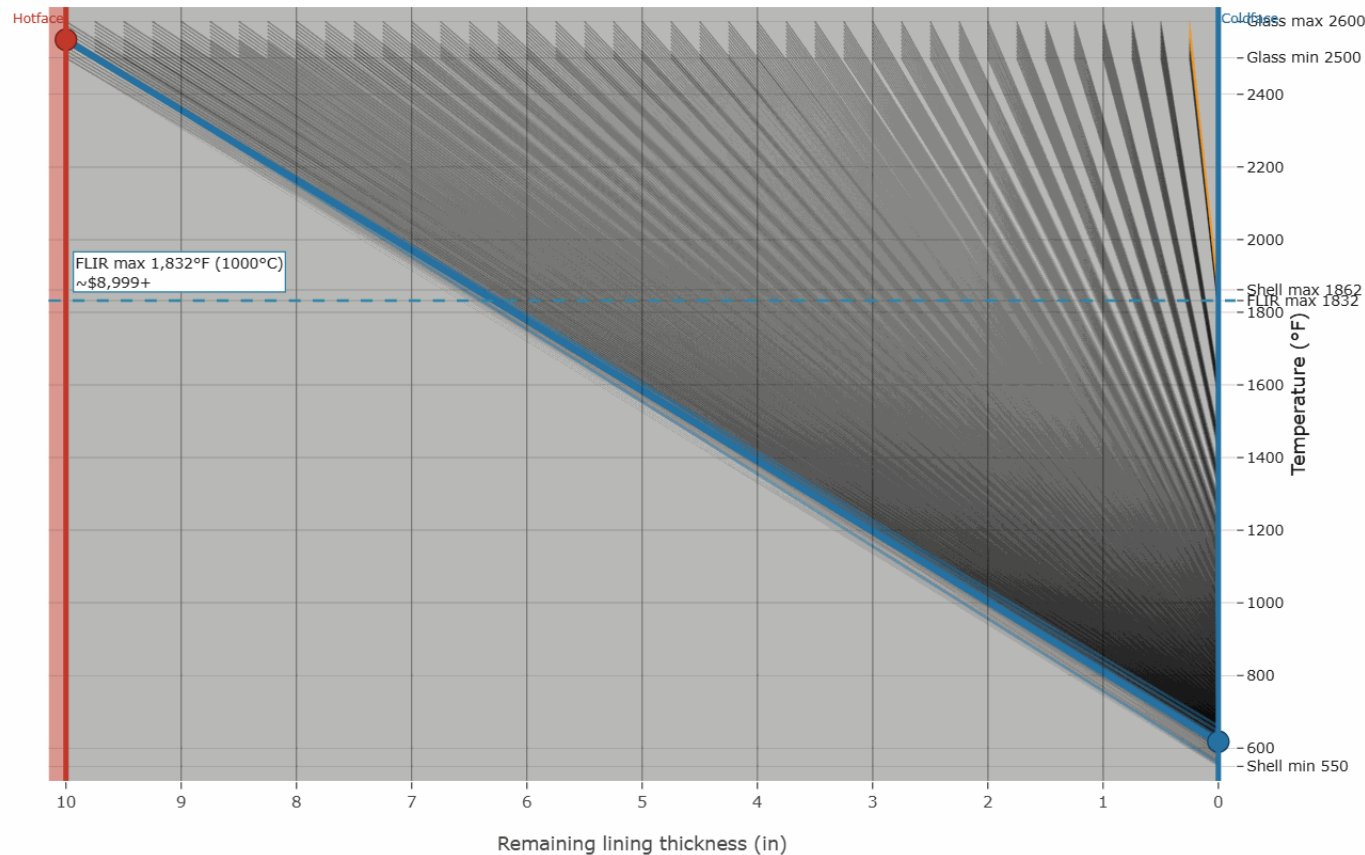
SEGMENTATION ANALYSIS

Volumes of interest can be segmented and summarized statistically for comparison across inspections.



3DEGREE - Reduced Order Modeling (ROM)

1-layer thickness cycle — 10 in | wind=30 glass HF=2550°F | shell=618°F



Thermal modeling can augment segmented temperature data to estimate residual refractory thickness.



So How Does The 3DEGREE Scanner Stack Up?

COMPARABILITY: designed into the spatial data structure

COVERAGE: mobile platform supports broad accessible-furnace coverage

COST: high scan rates + economical sensing hardware

CONTINUITY: still dependent on repeat manual inspection

**The technology appears sufficient, but
does the business model support this?**



Can 3DEGREE Empower Operators To Collect Their Own Data?

The missing component needed to enable repeatable analysis has been **localization**.

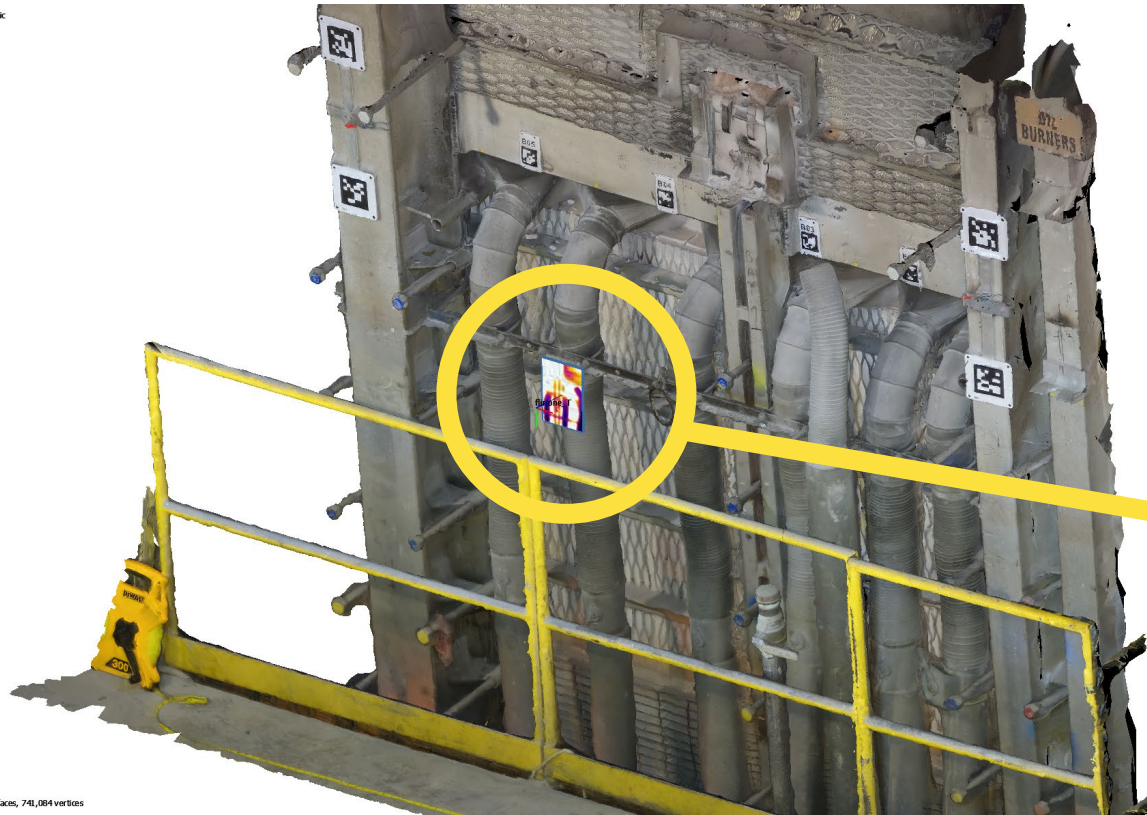
Thermal imagery provides poor localization on its own.

But a pre-existing 3D model and encoded fiducial markers allow even a single thermal image to be localized within the furnace coordinate system.



3DEGREE And Experiments In Client Collected Data

Orthographic



1,478,215 faces, 741,004 vertices

Snip: Axis, 3D

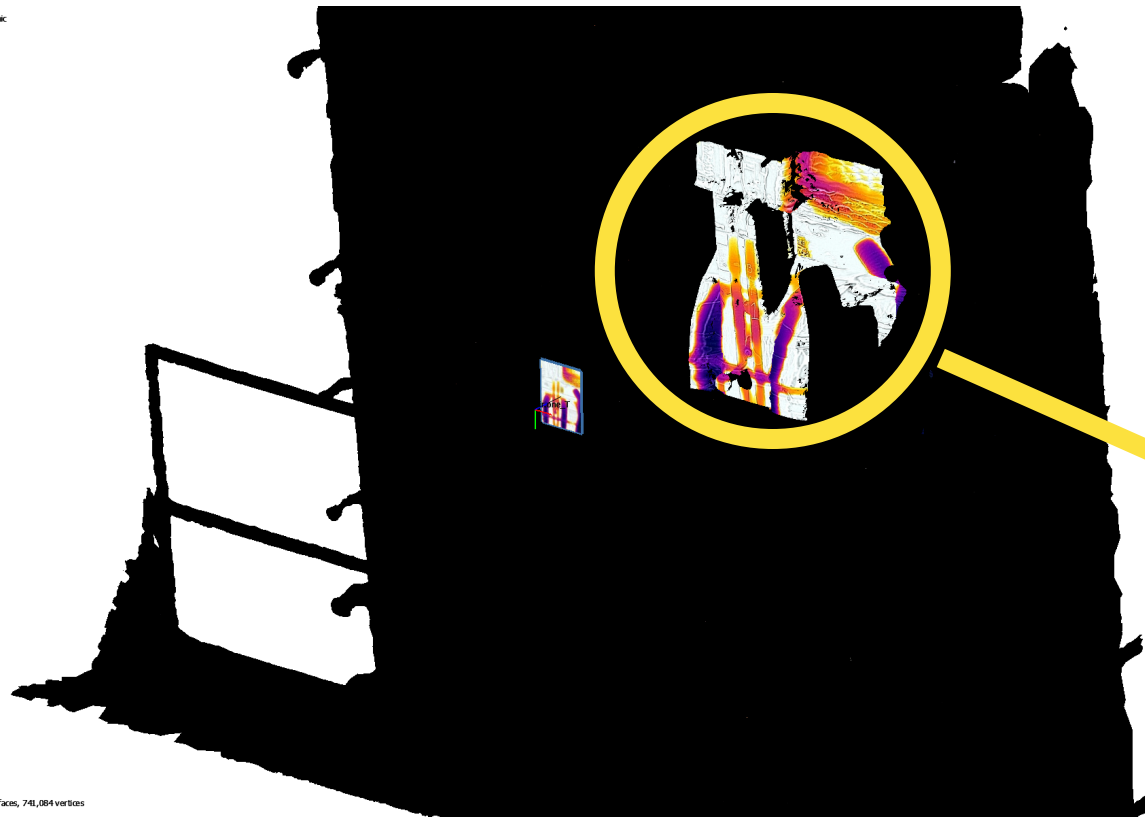


Localization of a single thermal image from a FLIR Handheld



3DEGREE And Experiments In Client Collected Data

Orthographic



1,478,215 faces, 740,084 vertices

Snap: Axis, 3D



Data translated to a 3-dimensional format for analysis



3DEGREE – From Measurement to Monitoring

TEMPERATURE MEASUREMENT IS MATURE

Economical technologies already exist to collect useful refractory temperature data.

LOCATION TURNS MEASUREMENTS INTO A HISTORIAN

Spatial registration makes repeated observations algorithmically comparable.

FREQUENCY TURNS A HISTORIAN INTO A MONITORING PROGRAM

Repeated collection and analysis create actionable refractory condition information.

QUESTIONS?

