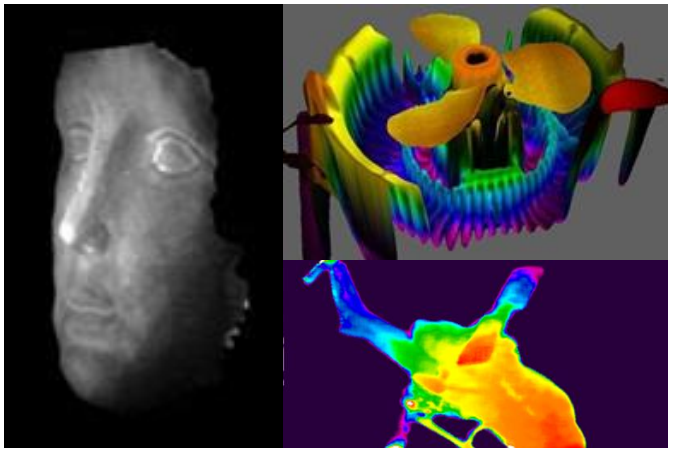
TetraVue



High speed 3D capture for Configuration Management

DOE SBIR Phase II

Paul Banks

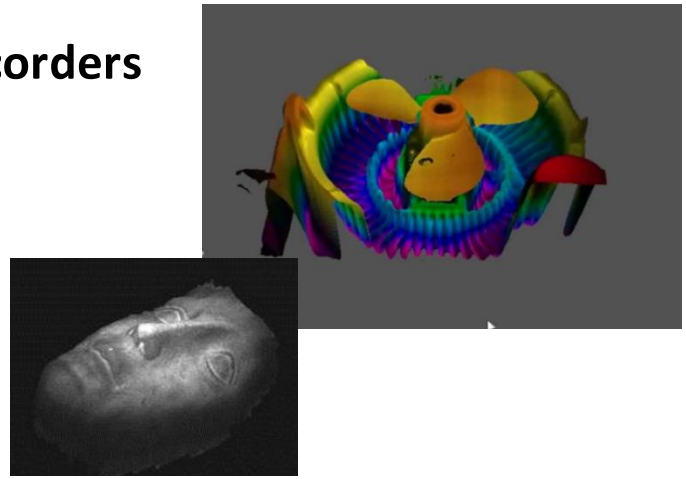
Paul.banks@tetravue.com

Advanced Methods for Manufacturing Workshop

September 29, 2015

TetraVue does high resolution 3D imagery

- **Founded in 2008 to make high resolution 3D camcorders a reality**
  - Simple instant capture of location of surroundings
  - Patented system technology
  - High resolution, long range, low power



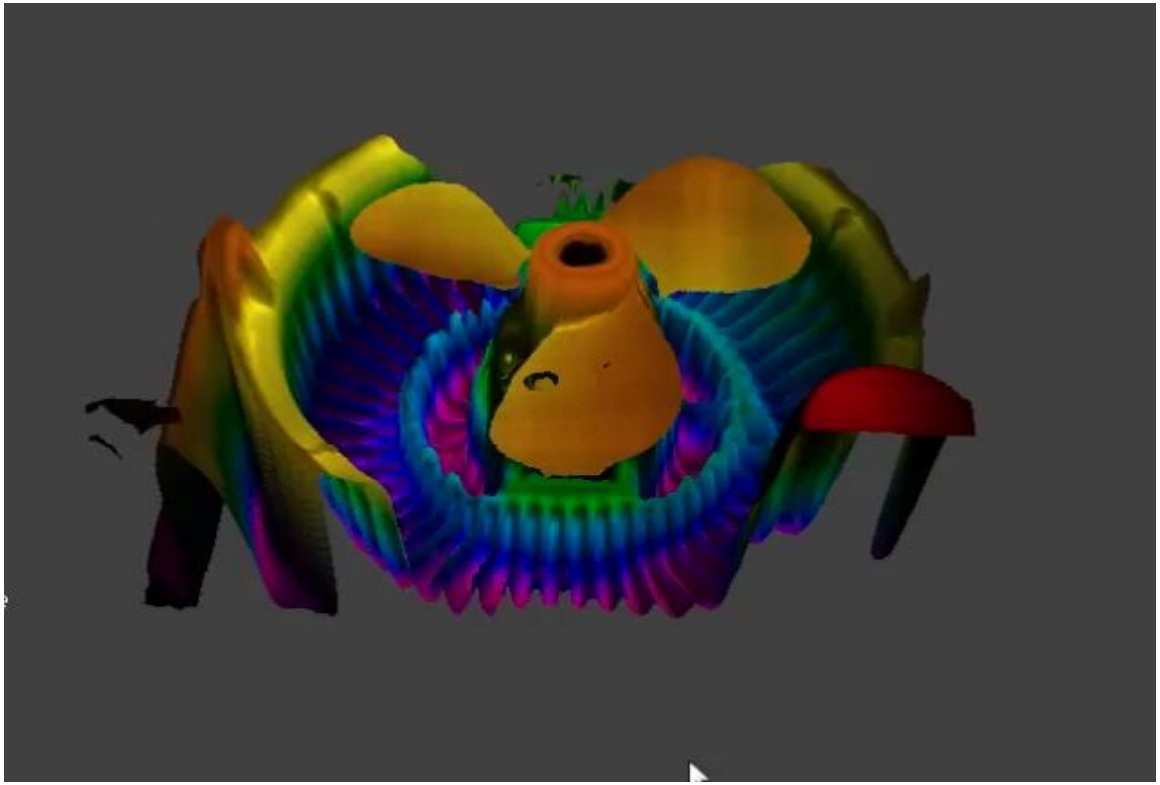
- **Technology team has demonstrated core technology**
  - Exceptional core team with world-class engineering partners
  - Technology projects to show utility for Mars landers, autonomous helicopters, biometrics, and industrial construction

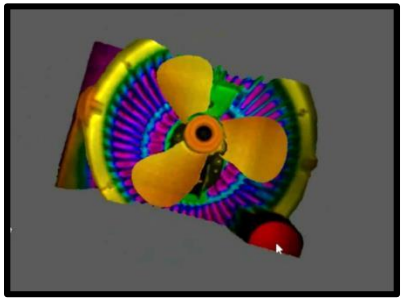
- **Beginning productization to create small, high resolution 3D camera product**

TetraVue

True high resolution 3D video is revolutionary

High resolution 3D video changes how machines & humans interact with the world





Acquisition point of view

6 m range, 12 fps, ~3 mm range resolution, 2 Mpx sensor

TetraVue has unique 3D capability in resolution, range, power & speed

TetraVue

Nuclear power plant configuration management requires a new solution

- **Modern configuration management requires as-built information**
  - Accurate, up-to-date
  - Cost-effective

Nuclear facilities have high density of components & tight tolerances

Existing solutions are too costly & slow.

- **Existing approaches (3D laser scanners) require extensive setups and post-processing**
  - 1000s of scans per facility
  - Manual registration to plant coordinate system
  - Separate imagery for component ID
- **New tablet scanners are limited**
  - Short range operation
  - Slow acquisition
  - Poor resolution
  - But less expensive ($5 – 10K + software)

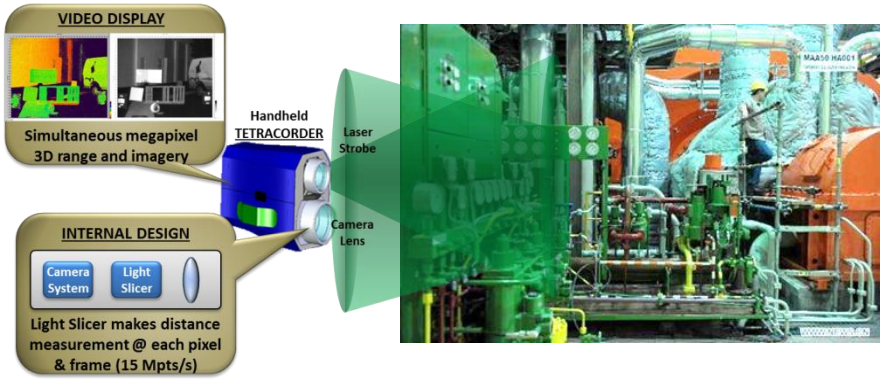
TetraVue's 3D camera technology promises automate registration without setups
- Imagery & coordinate information from a single sensor

Megapixels, 30 m range, low power

TetraVue

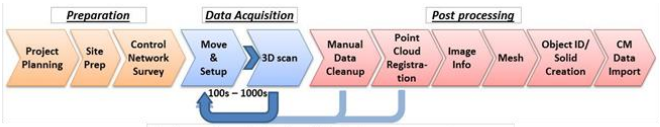
Phase II will demonstrate the value & utility of acquiring 3D data from a moving platform

- 3D coordinate and image capture from a moving platform.
  - <Improve 2X with 2X FOV in handheld>
- 3D frame registration into a project-based reference frame
  - <Improve accuracy & speed>
- Determine control network density required.
  - <Confirm 100 m between control points>
- Demonstrate integration of data in CAD software for comparison with design
  - <Near real-time integration>
- Demonstrate in test environment relevant to nuclear power plant construction.
  - <End-to-end live demo>
- ID fieldable design requirements.
  - <Update from input from stakeholders>

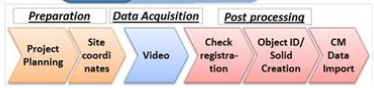


Phase II handheld 3D camera

Traditional Workflow for 3D scanning



Potential TetraCorder Workflow



Phase II objectives will demonstrate practicality of high resolution 3D video for cost-effective configuration management

- 1” accuracy to plant system [ultimate goal is 2-4X better for critical dimensions]
- Eye-safe (class 1M)
- Max Range 20 – 30 m
- Near real-time 3D models of complex structures
- 10 - 45°C operation
- Demonstrate 1 person operation/handling

- **Improve camera performance by 3X over Phase I**
- **Build handheld, single person operation 3D camera prototype**
- **Show near-real-time, accurate model generation**

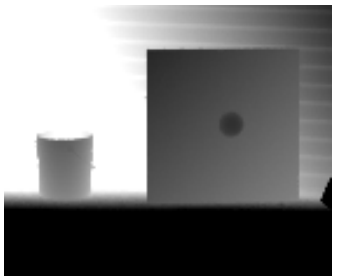
End-to-end demonstration: incorporate 3D model into common CM software in < 4X the capture time

TetraVue

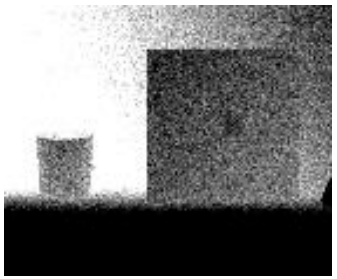
Pixels matter

Impact of image & range noise (and therefore distance) is much less with higher pixel counts

Simulated depth images



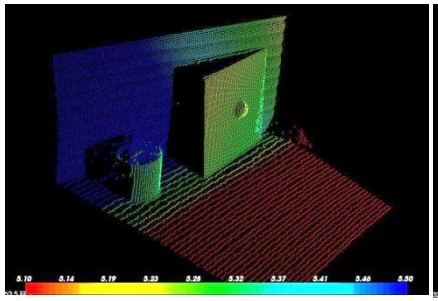
No depth noise



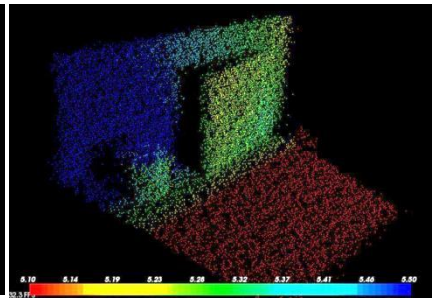
4 cm depth noise

140 px x 116 px

3D rendering of same data

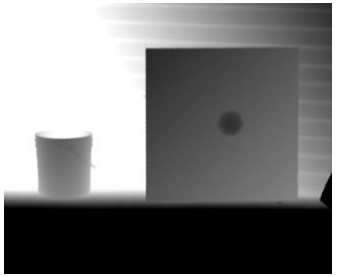


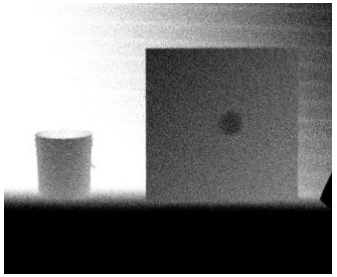
No noise



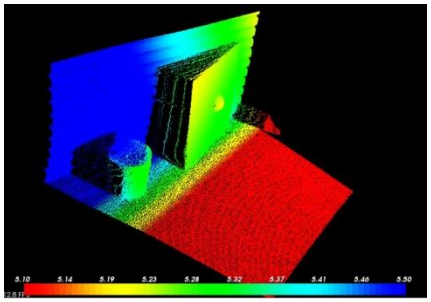
With BLF filter

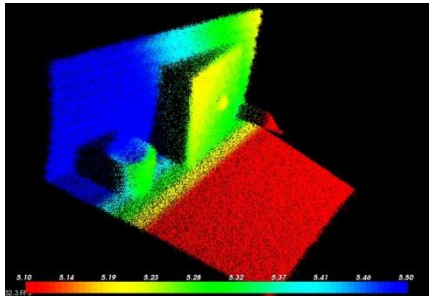
4 cm noise



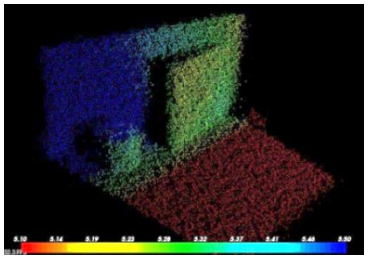
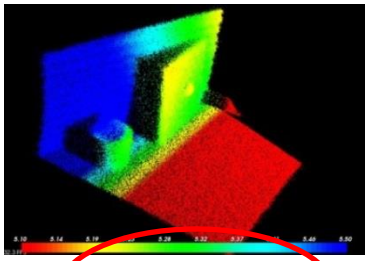


700 px x 580 px





4 keys for 3D: pixels, range, power, & cost

	State-of-the-Art	TetraVue
More Pixels (Megapixel)	 10,000 – 40,000	 2,000,000
More Range (10 – 100+ m)	< 5 m	100+ m
Less Light Power Electric power 4-100X	2,260 W*	0.4 W* (Quantum limited)
Low cost	?	< $200 (high vol)

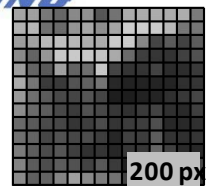
*For 1Mpx @ 50 m, 10% reflectivity

An optical approach to TOF 3D imaging promises makes high resolution 3D imagery possible

TRADITIONAL

MIT Lincoln Laboratory

BOEING



< 40,000 pixels

SAMSUNG

Google

and many others…

High bandwidth (GHz) time-sensitive

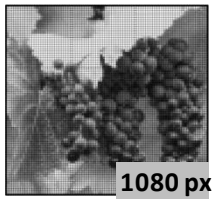
Pixel count

Think different

Medium Bandwidth (<15 MHz) optical

REVOLUTIONARY

Optical TOF



Stock CMOS imaging sensor
--Leverages CMOS sensor improvements

2,000,000 pixels
20 – 100+ m range

TetraVue

$100Ms for ~10 – 40 kpx

Development cost to date:

$3M for 2Mpx

Scaling has been VERY challenging

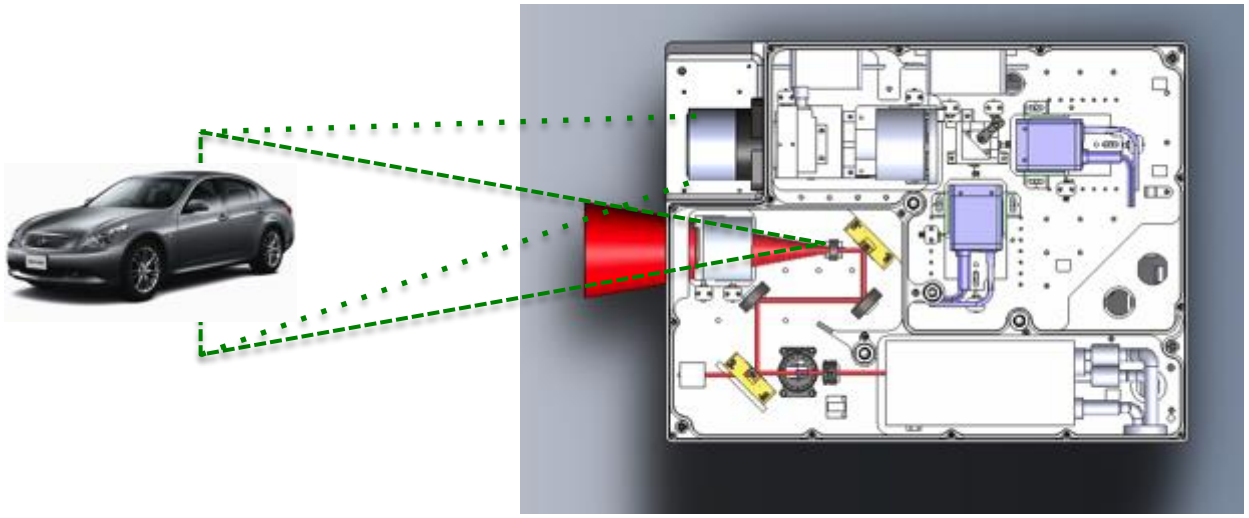
Known productization steps

Path to monolithic 3D sensor:

TetraVue

TetraVue's 3D Camera Technology uses optics to measured time and distance

Instantaneous 3D image capture with a single aperture



- Patented "light slicer" technology
- Extended laser strobe (no blurring/no scanning)
- Simultaneously capture information for all pixels
- Camera-like HD imaging: coordinates & image
- Low latency—"instant" decisions

IMPACT

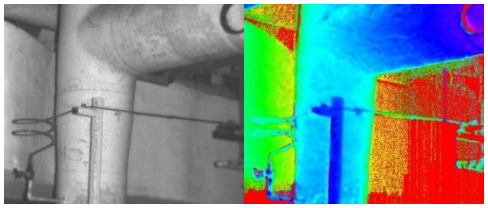
- 10 – 100X more pixels
- 10 – 100X longer ranges
- 25 – 100X less power
- 100X lower development cost
- Scene captured instantly
- Path to low cost 3D sensor

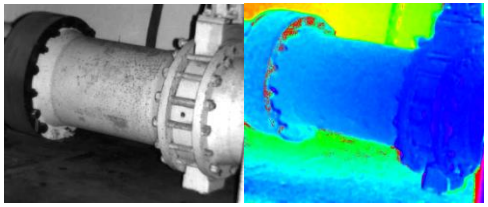
TetraVue

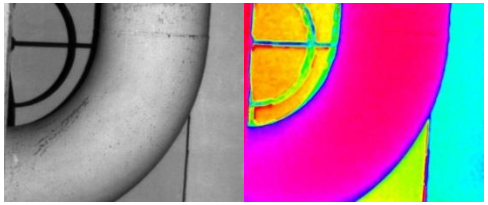
3D video imagery from nuclear plant

TetraVue Prototype 3D camera at site

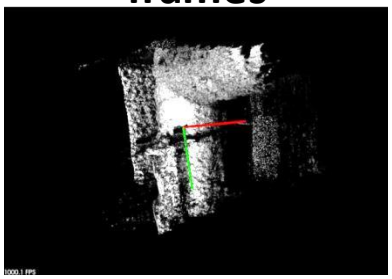
Simultaneous Intensity & range maps at 10 fps

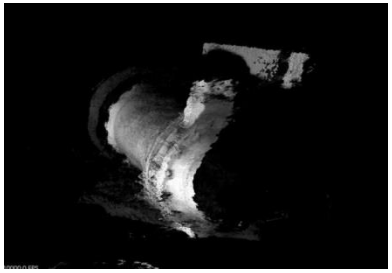


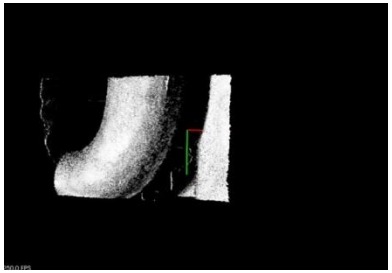




Generation of 3D object frames

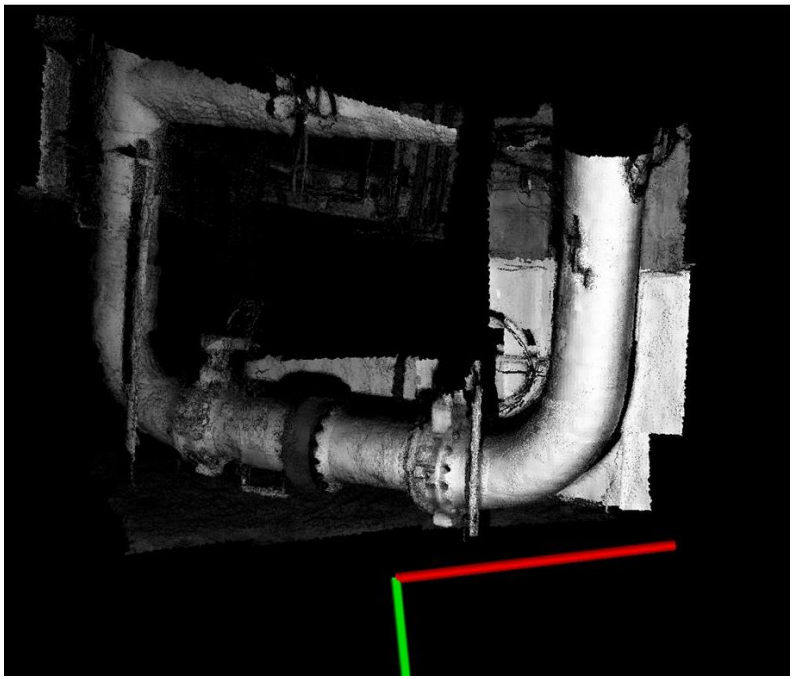




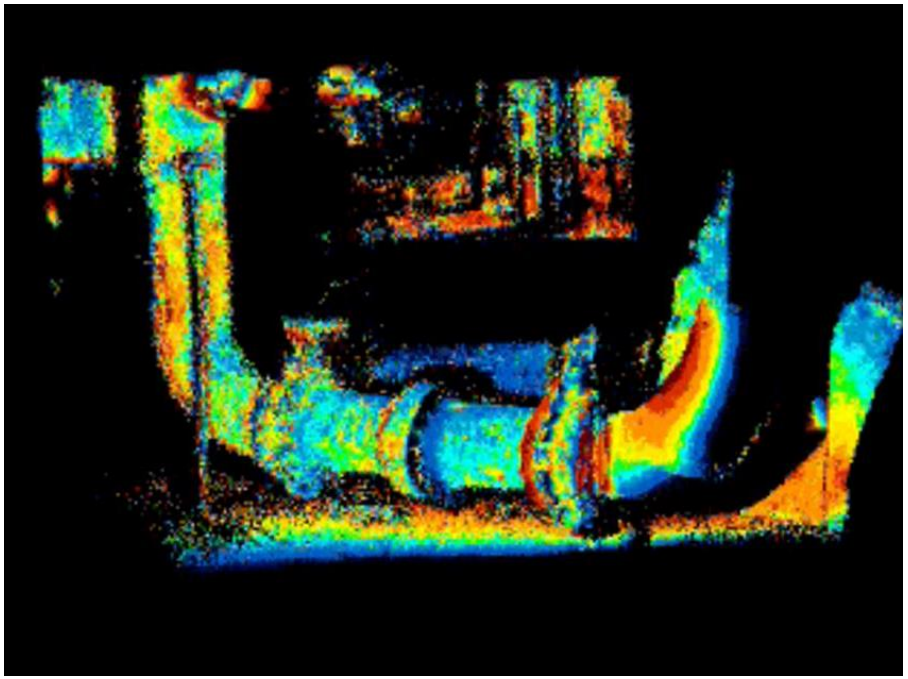


Automated model creation from 100 frames compares well with prior as-built 3D data

Registered 3D model from video



Comparison (color indicates error)



Registered model within 2” of prior as-built measurements

- **DOE Phase II will demonstrate engineering grade performance**
  - **< 1” accuracy to plant coordinate system over extended area**

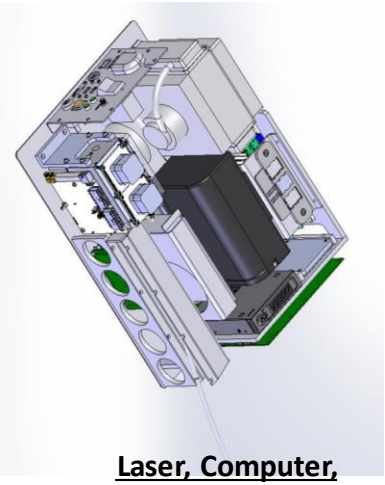
TetraVue

Phase II 3D camera is designed to allow 1-person operatio in congested environments

- Handheld camera + backpack
- > 45 min operation on battery
  - 5 min can cover 6000 m^2 (90% overlap)
- Sub-cm resolution and accuracy out to 10 m
  - Operational to > 30 m
- Operation like a camcorder

Camera & display
6” x 6” x 6”
7 lb

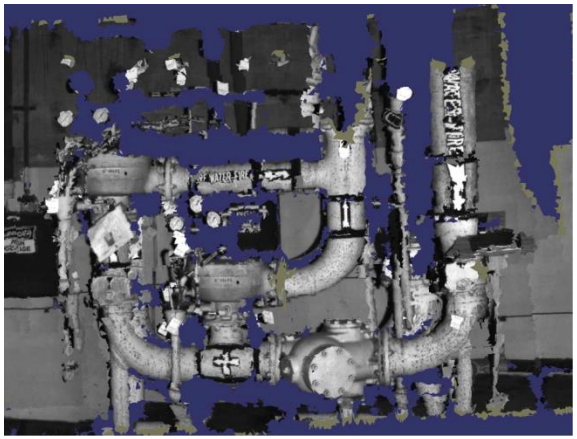
- Optics optimized & miniaturized
- Minimal electronics miniaturization



Laser, Computer, timing & battery
6” x 10” x 16”
25 lb

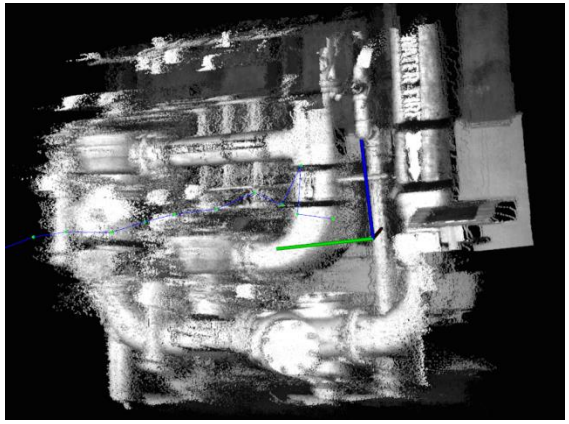
TetraVue

3D Registration is pursuing 2 parallel paths to achieve project goals



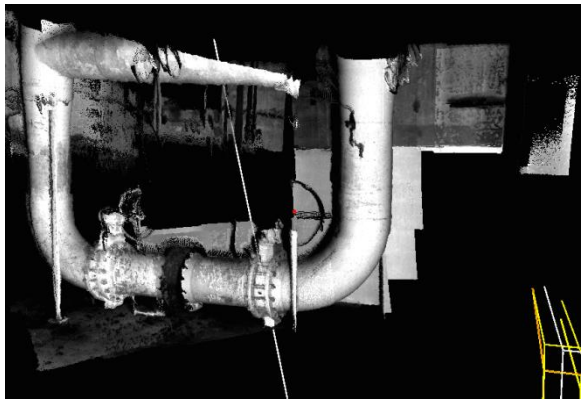
PRELIMINARY RESULTS FROM Phase I
Texture applied to mesh but created registered surface relatively inaccurate

Modified open source



Approach I

Modified commercial product



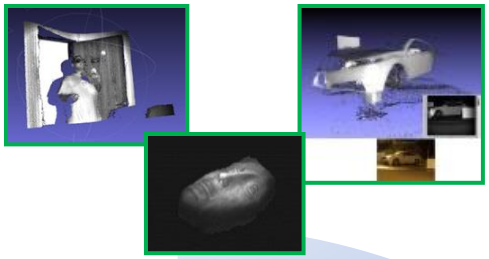
Approach II (Dot Product)

TetraVue

Live registration demo

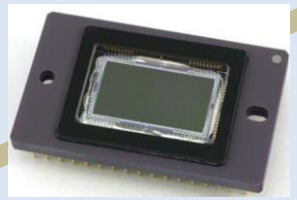
Product will be ubiquitous low-cost, long range, megapixel 3D sensor and cameras

High resolution monolithic sensors can now be realized with TetraVue's optical TOF technology



Technology Prototypes

Productization



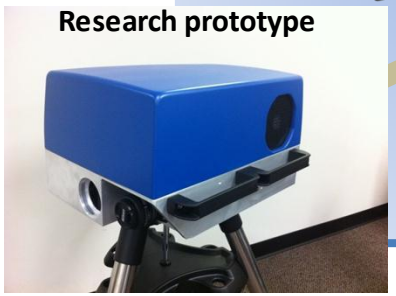
Monolithic high (Mpx) resolution 3D sensor that can span product lines & markets

We are here

Industrial prototype
June 2015

2.5 in

Research prototype



Low cost, 3 W_{elec}

2015 2016 2017 2018

TetraVue

What is missing in the Information Age?

Design/Virtual

- Autonomy
- CAD
- Machine Vision
- CG
- Visual f/x
- Augmented Reality
- Virtual Worlds
- Avatars

Reality/Live

- Objects
- Scenes
- Live Action
- Equipment
- As built
- People

REALITY MEETS DESIGN