Optimizing the Test Space for Multi-Band Optical Tracking Systems (MBOTS)

Michael Horii

Photo-Sonics, Inc.

Overview

- Multi-Band Optical Tracking Systems (MBOTS)
- Predictive model for MBOTS performance
- Definition of p(test success)

What are MBOTS?

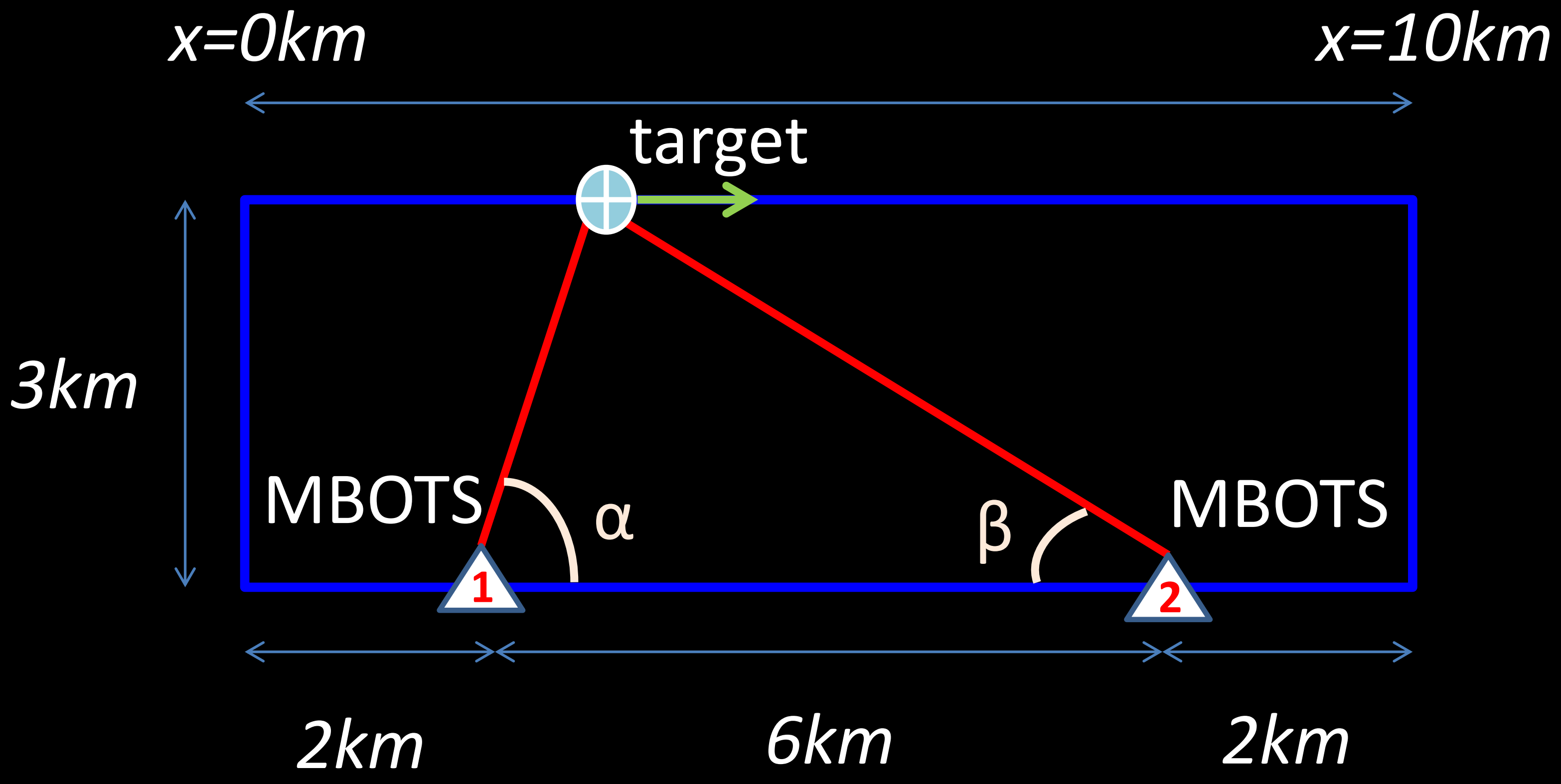
Capabilities

- Track objects
- Record
  - High-speed images
  - Pointing angles
  - Time-space-position info (TSPI)
  - Spectral data

Applications

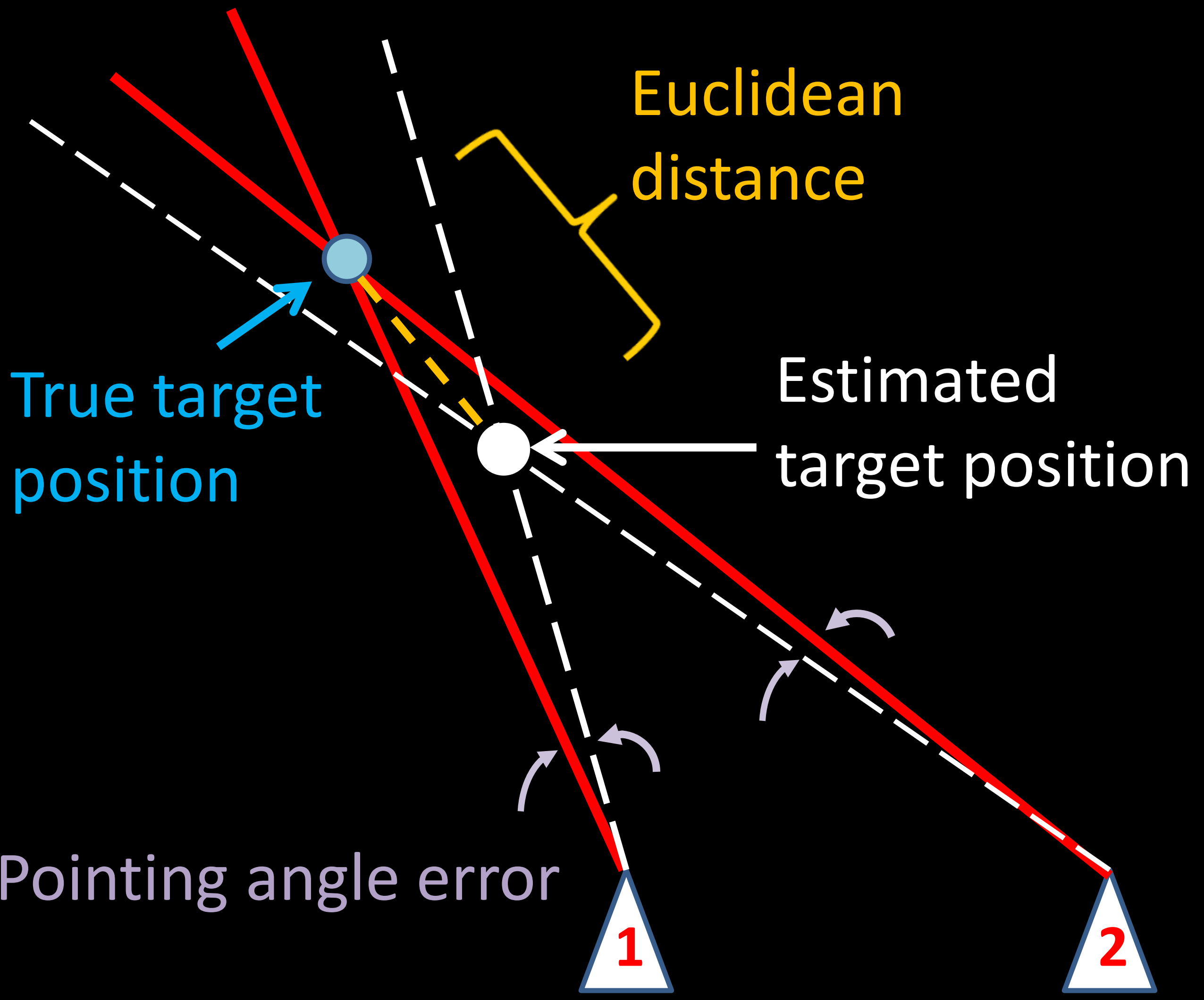
- Laser designation
- Missile testing
- Product Evaluation
- Satellite tracking
- Fire Control
- Surveillance

Test Scenario Geometry



Requirement: Estimate target position to within 1 meter

Error Defined



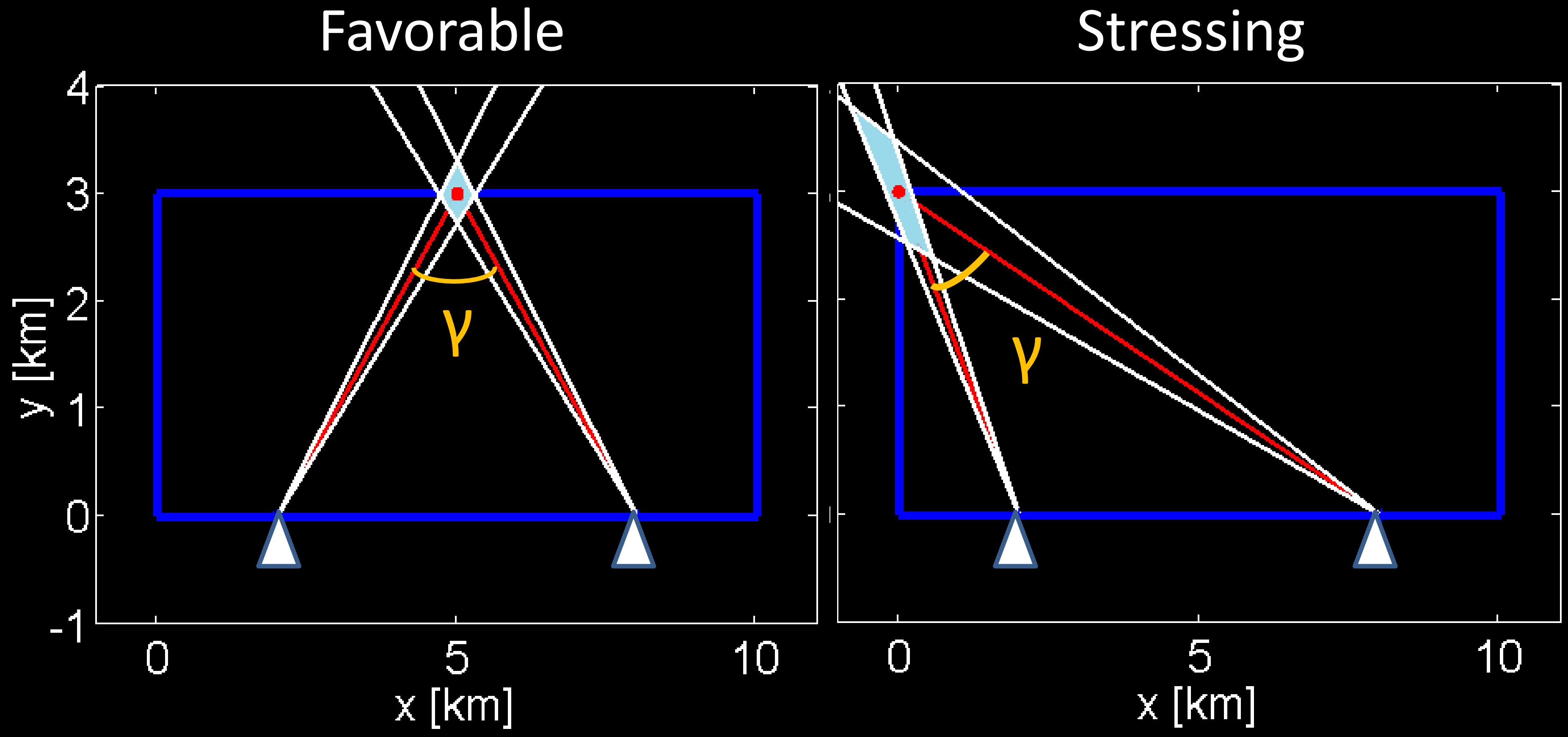
Euclidean distance

True target position

Estimated target position

Pointing angle error

Uncertainty and Viewing Geometry



As γ decreases, area of overlap (uncertainty) increases

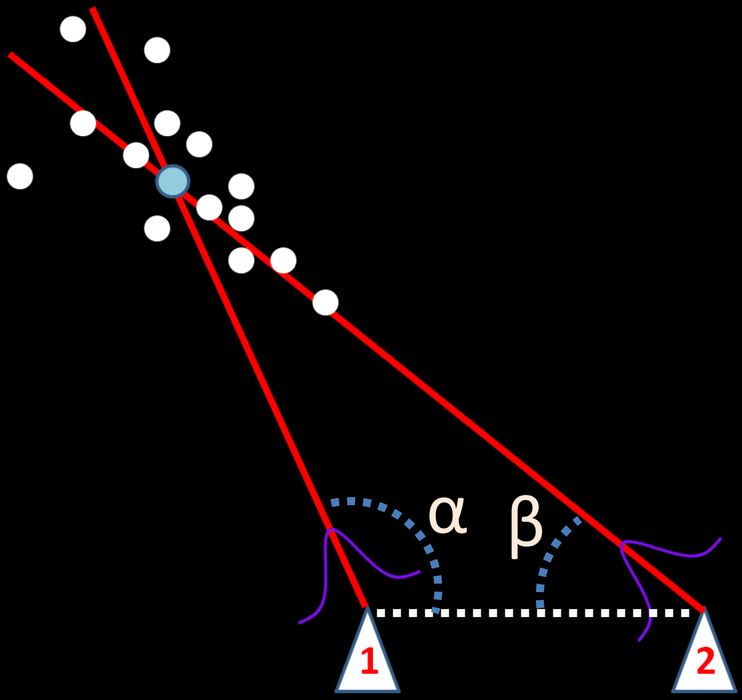
Monte Carlo Approach

- Draw angles from

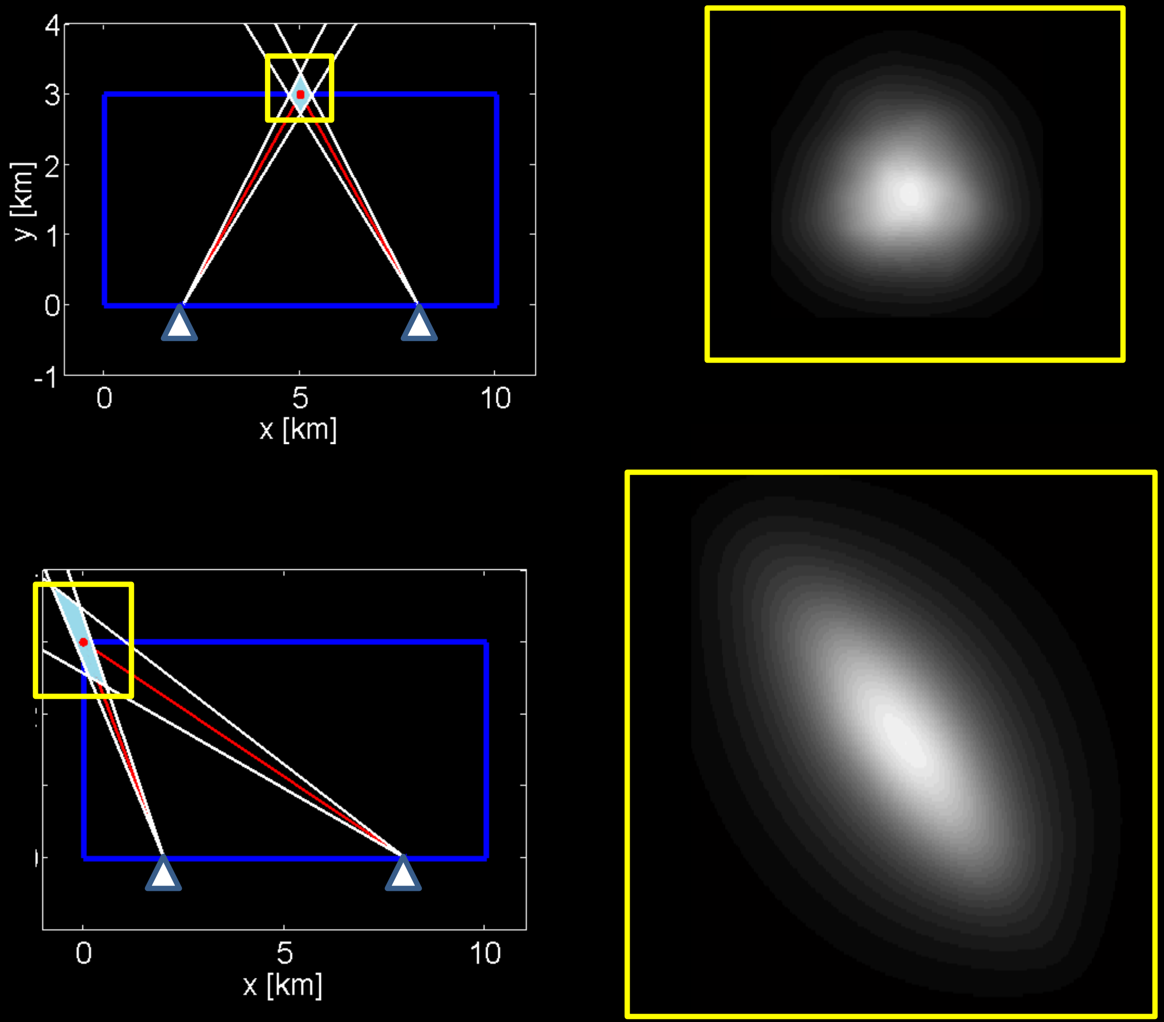
$$\alpha_i \sim N(\mu = \alpha, \sigma^2),\ i = 1,2,\ldots,n$$

$$\beta_i \sim N(\mu = \beta, \sigma^2),\ i = 1,2,\ldots,n$$

- Determine intersection point between lines-of-sight
- Calculate Euclidean distance between true and estimated target position

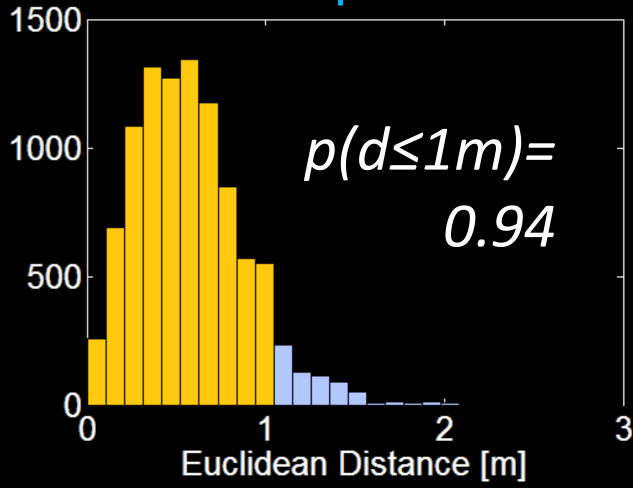


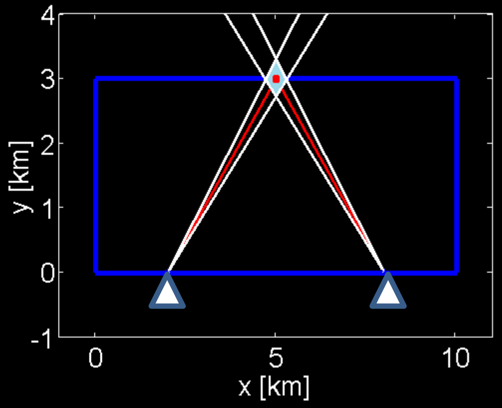
Visualizing Positional Uncertainty



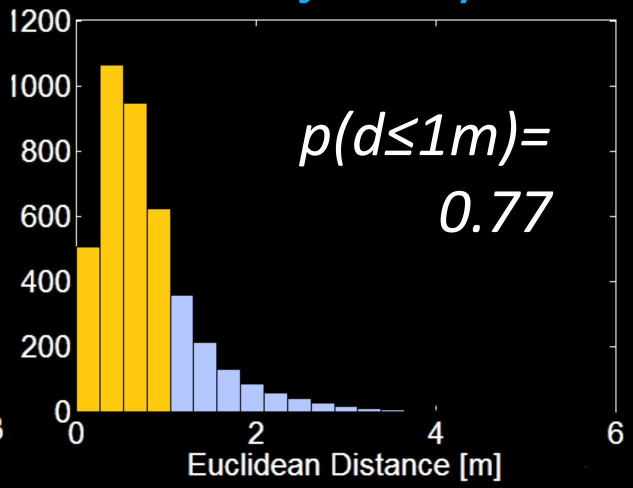
Euclidean Distance Distributions

Target at midpoint



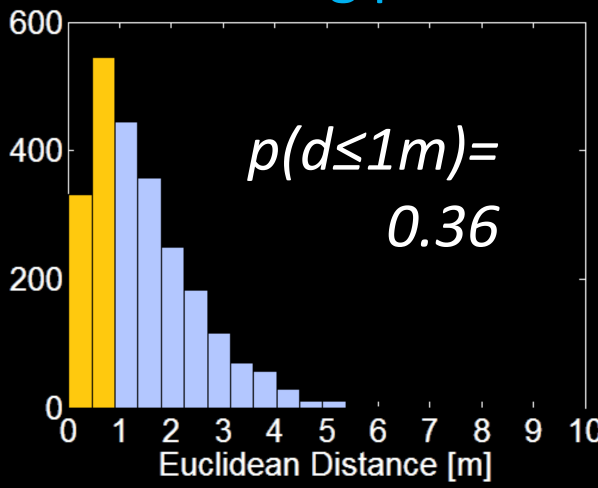


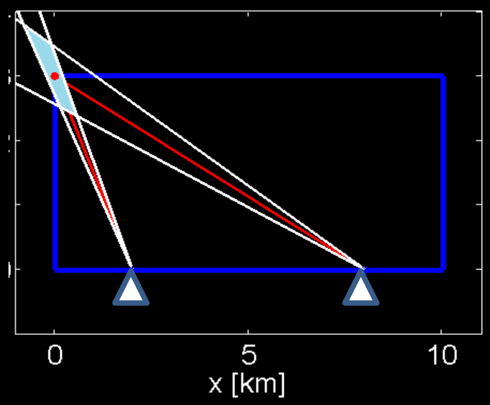
Target across trajectory



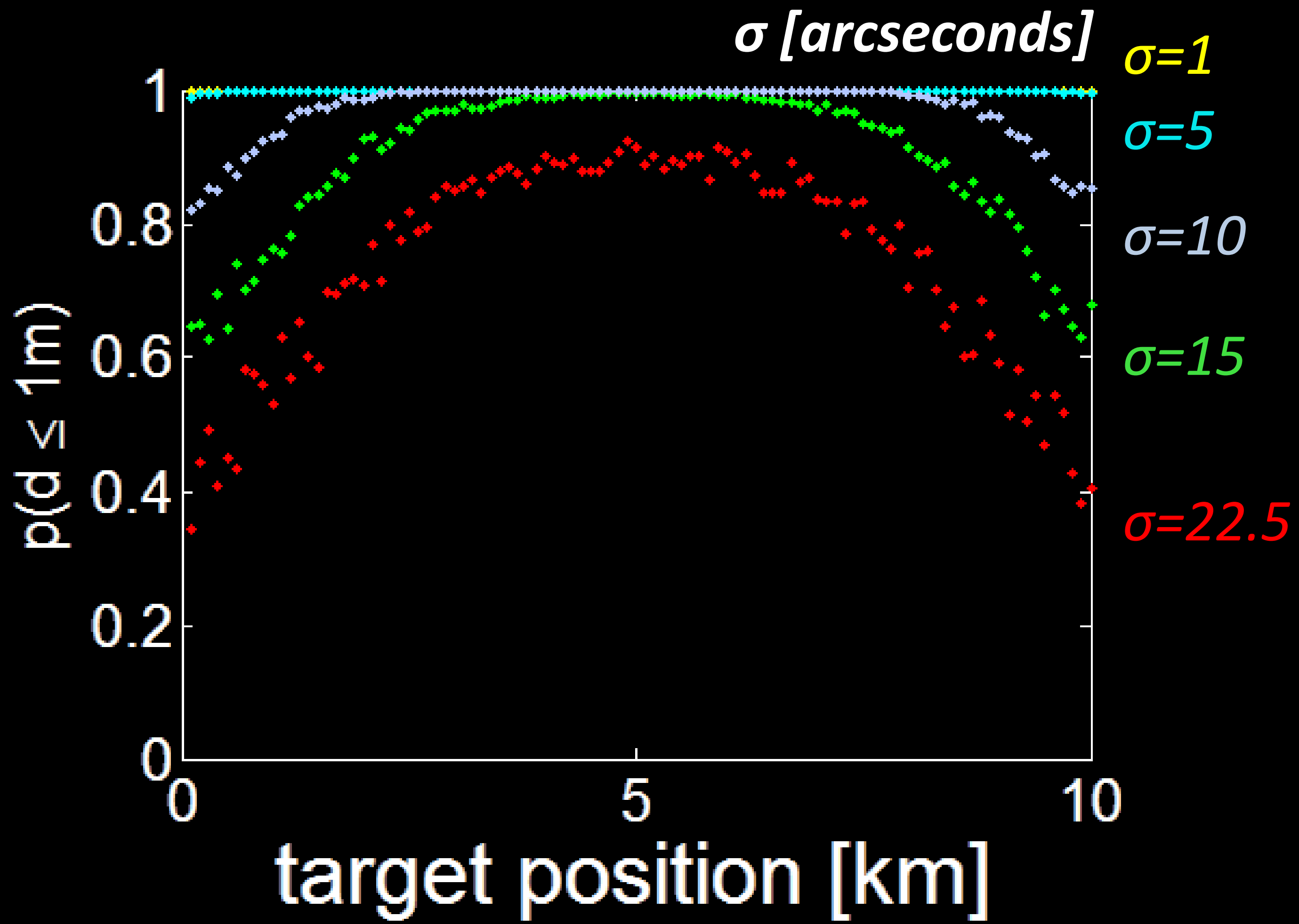
What do we want to optimize?

Target at starting point





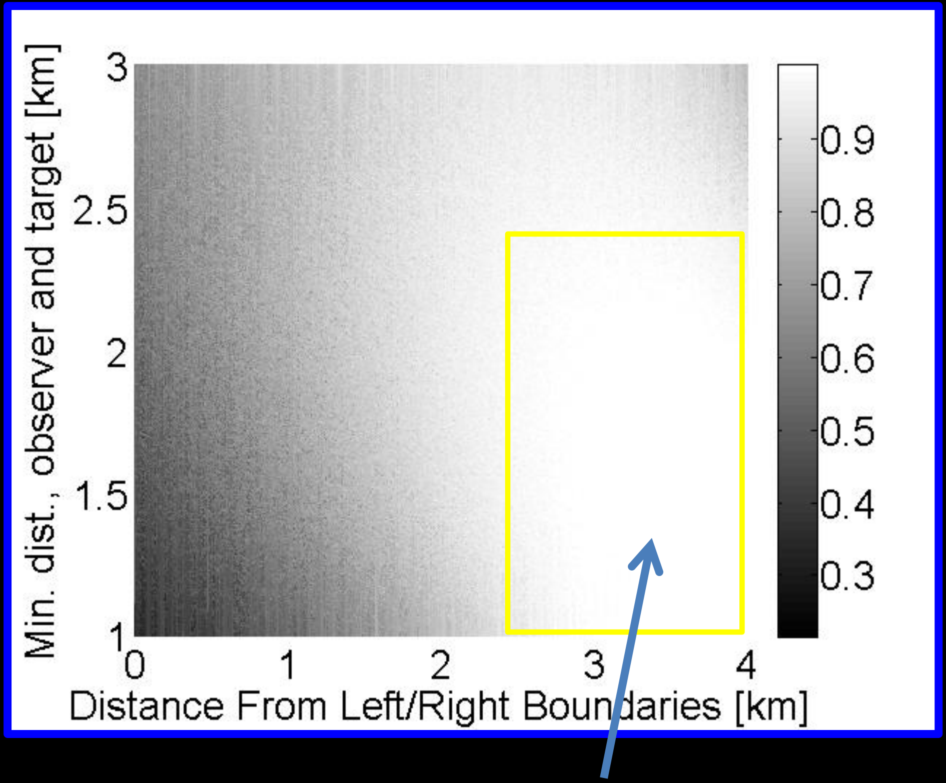
Positional Accuracy vs. Error Budget



Increasing Uncertainty

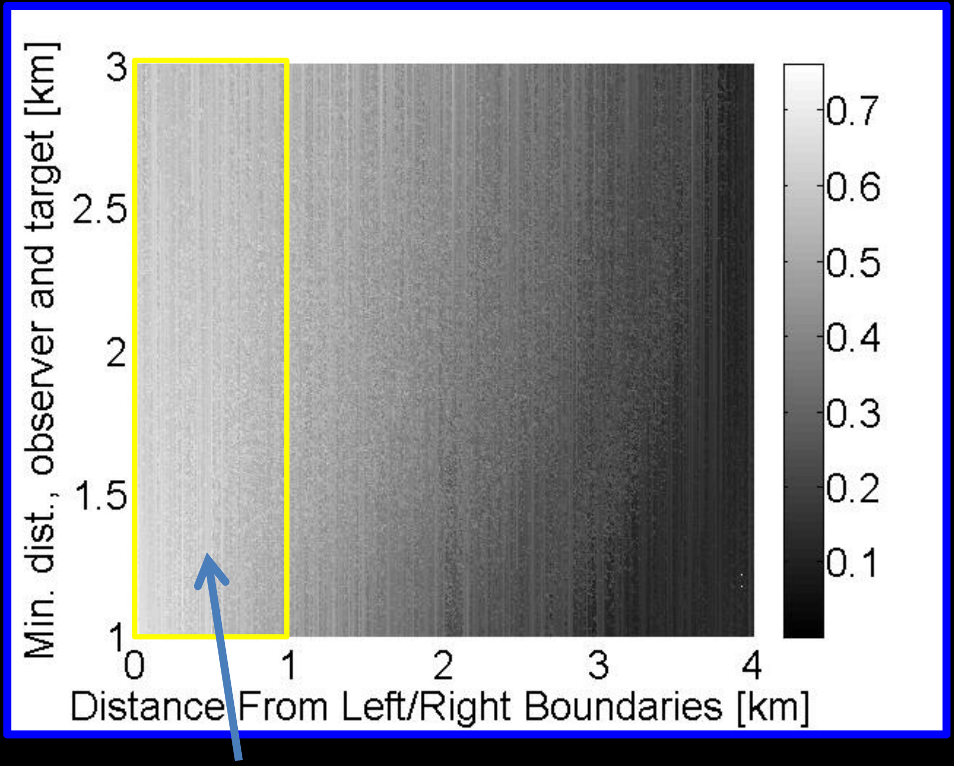
Determining Optimal Site Placements

Target at Midpoint of Trajectory



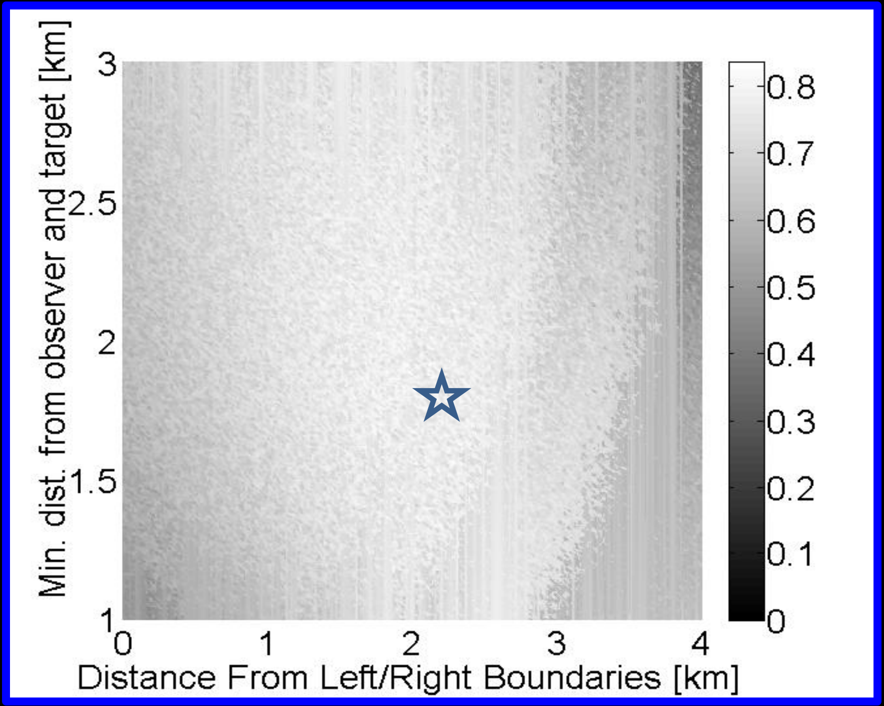
Wide bounds,
High accuracy

Target at Starting Point of Trajectory



Favors the edges,
Reduced accuracy

Optimal Site Placement Across Trajectory

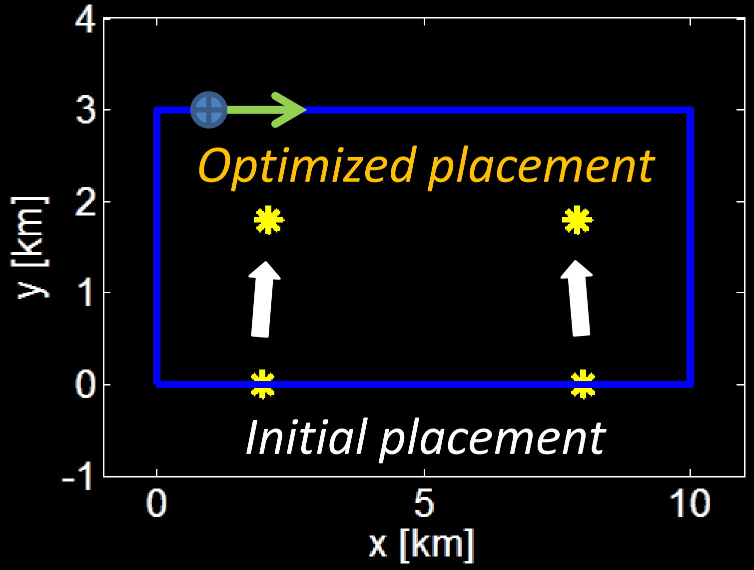


Optimal MBOTS location:

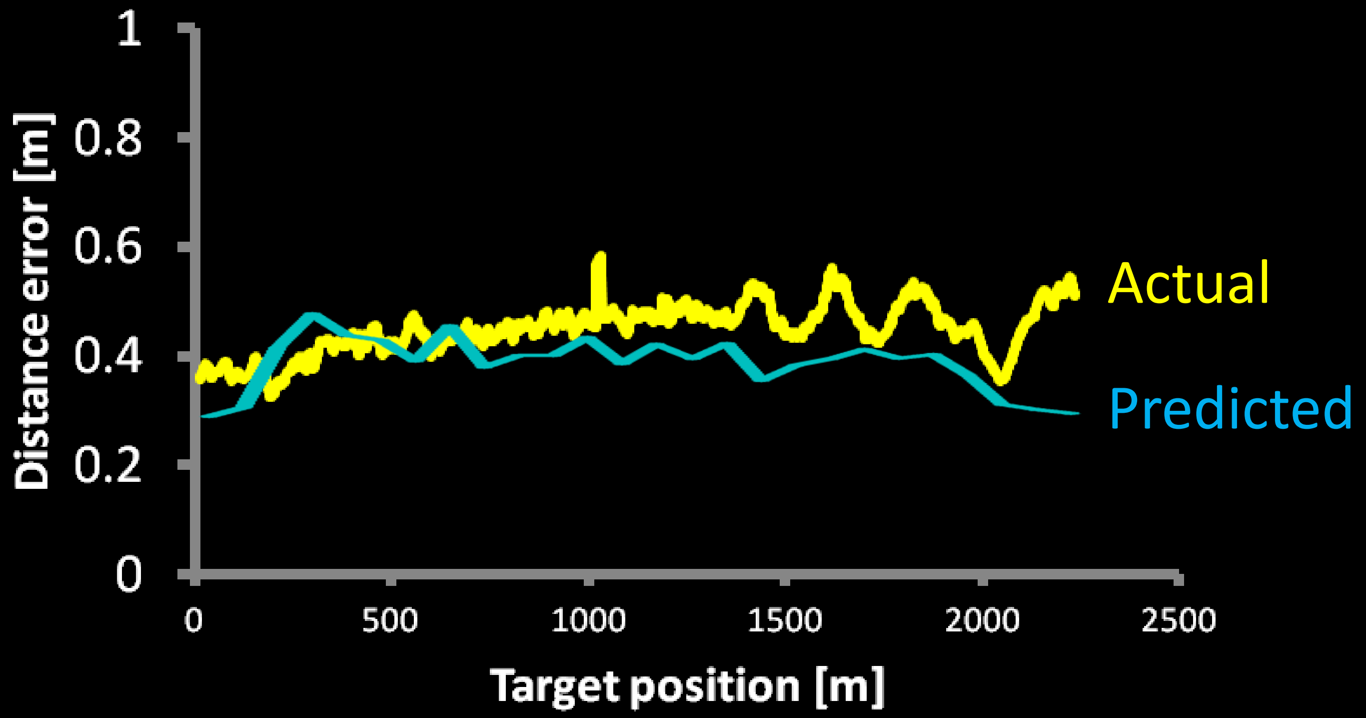
(x_1,y_1) = (2.1 km, 1.8 km)

and

(x_2,y_2) = (7.9 km, 1.8 km)



MBOTS Positional Accuracy: Predicted vs. Actual

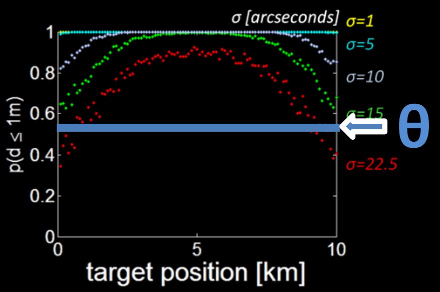


**Data from a site-acceptance test for the Photo-Sonics Mobile Multi-Spectral TSPI System (MMTS), White Sands Missile Range, 2012*

How To Define Success?

Position error ≤ 1m

Viewing geometry



$E \equiv p(\text{Position error} \leq 1\text{m}) \geq \theta$

Conditionally

Probabilistic success

$p(\text{success} \mid \theta, \sigma) = p[\, E \mid \theta, \sigma \,]$

Way Forward

- MBOTS system accuracy model
  - – Future enhancements
    - 6 degrees-of-freedom (DOF) trajectory propagator to support motion dynamics, complex trajectories
    - Modeling of optics, auto-tracker
    - Approach is extensible to multiple MBOTS
- Approach for defining p(test success)
  - – Result may be used as evidence for T&E resource allocation

Backup


MBOTS
object
test
system
model
track
tracking
error
needs
requirement
trajectories
systematic
estimation
testing information
auto-tracking
wide
paper
common
configuration
real-time
theoretical
obtain
objects
tracker
need
e.g
requirements
dynamics
multiple
accuracy
sources
parameter
viewing
calibration
and/or
provide

References

1. Downey, G.; Stockum, L. “Electro-Optical Tracking Systems Considerations,” <u>Acquisition, Tracking and Pointing III</u>, Vol. 1111, 1989.
2. Joint Range Instrumentation Accuracy Improvement Group, “IRIG Optical Tracking Systems Calibration Catalog,” Document 755-99, Secretariat, Range Commanders Council, White Sands Missile Range, New Mexico, February 1999.
3. Das, R.K. “Test and Evaluation of Tactical Missile System Using Electro-Optical Tracking System,” <u>ITEA Journal</u>, 30, 2009, 143-148.

Mobile Multi-Spectral TSPI System (MMTS)

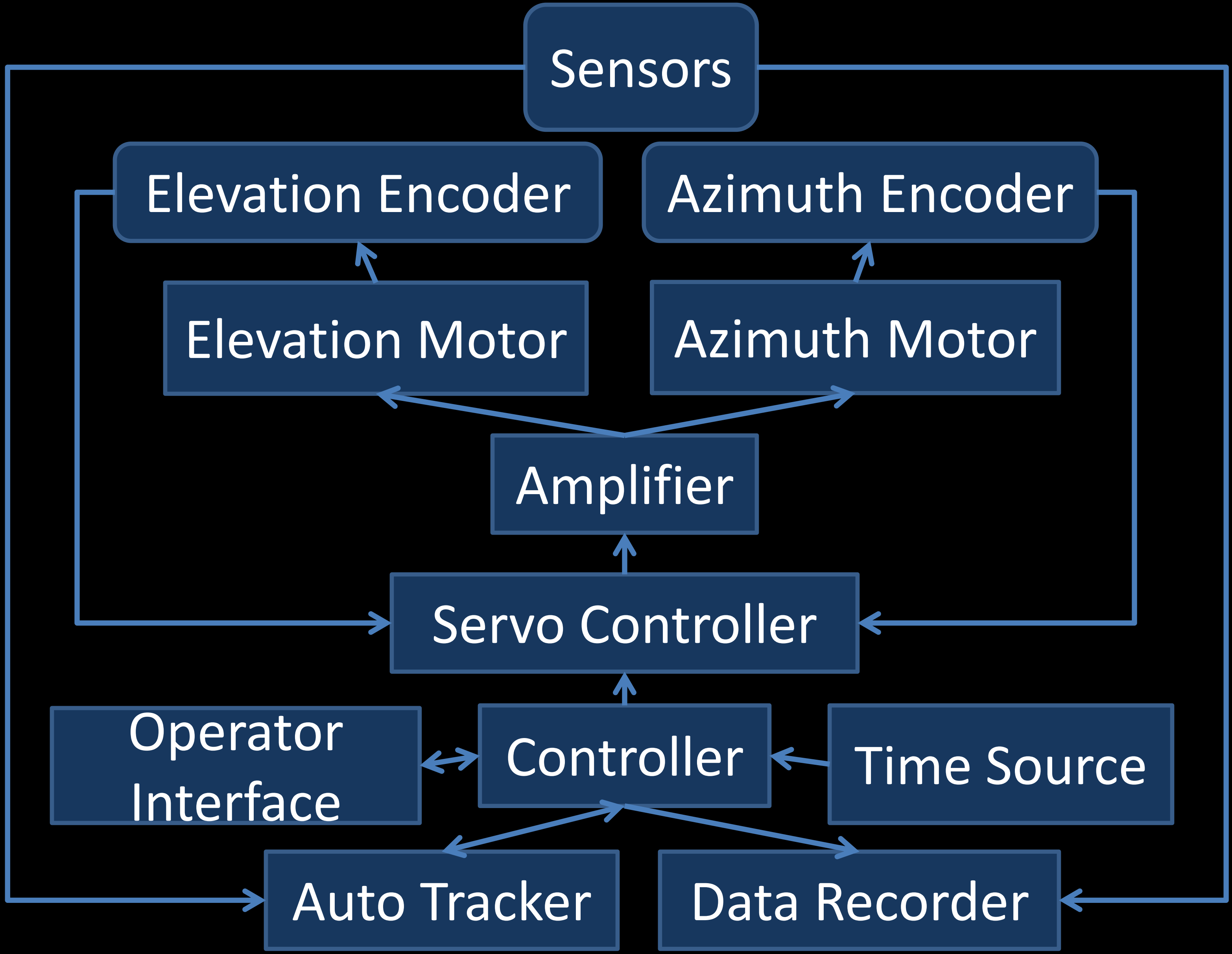
Specifications	
Nominal Payload	600 lbs.
Maximum Payload	1000+ lbs. with reduced accuracy and performance
Standard Configuration	On-axis optical payload; no man-on-the-mount
Optional Configuration	On-axis optics with off-axis radar
Azimuth Torque	1500 ft lbs
Elevation Torque	2 x 300 ft lbs
Azimuth, Elevation Acceleration	100+ degrees/sec^2 with nominal payload
Azimuth, Elevation Velocity	100+ degrees/sec
Weight	6500 lb. trailer-mounted pedestal with single axle
Dimensions	123L x 85W x 80H inches (plus 21" trailer tongue)
Encoder	24-bit absolute position optical encoder with 23-bit quadrature output for velocity

Features:

- Fully Integrated Pedestal and Sensor Control Software
- Real-Time TSPI data output
- Single station solution
- Sensors and System Time-Synchronized to IRIG @ 250 Hz
- Dual gate auto-tracking with Camera Link @ 250 Hz
- Remote Control Console
- Digital Servo Amplifier

Calibration	***Turn & Dump***	***Star Calibration***
No Radar	X	X
Radar on Top		X
Radar on Side	X	X

MBOTS Key Components



Sensors

Elevation Encoder

Azimuth Encoder

Elevation Motor

Azimuth Motor

Amplifier

Servo Controller

Operator Interface

Controller

Time Source

Auto Tracker

Data Recorder

Test Value Quantification

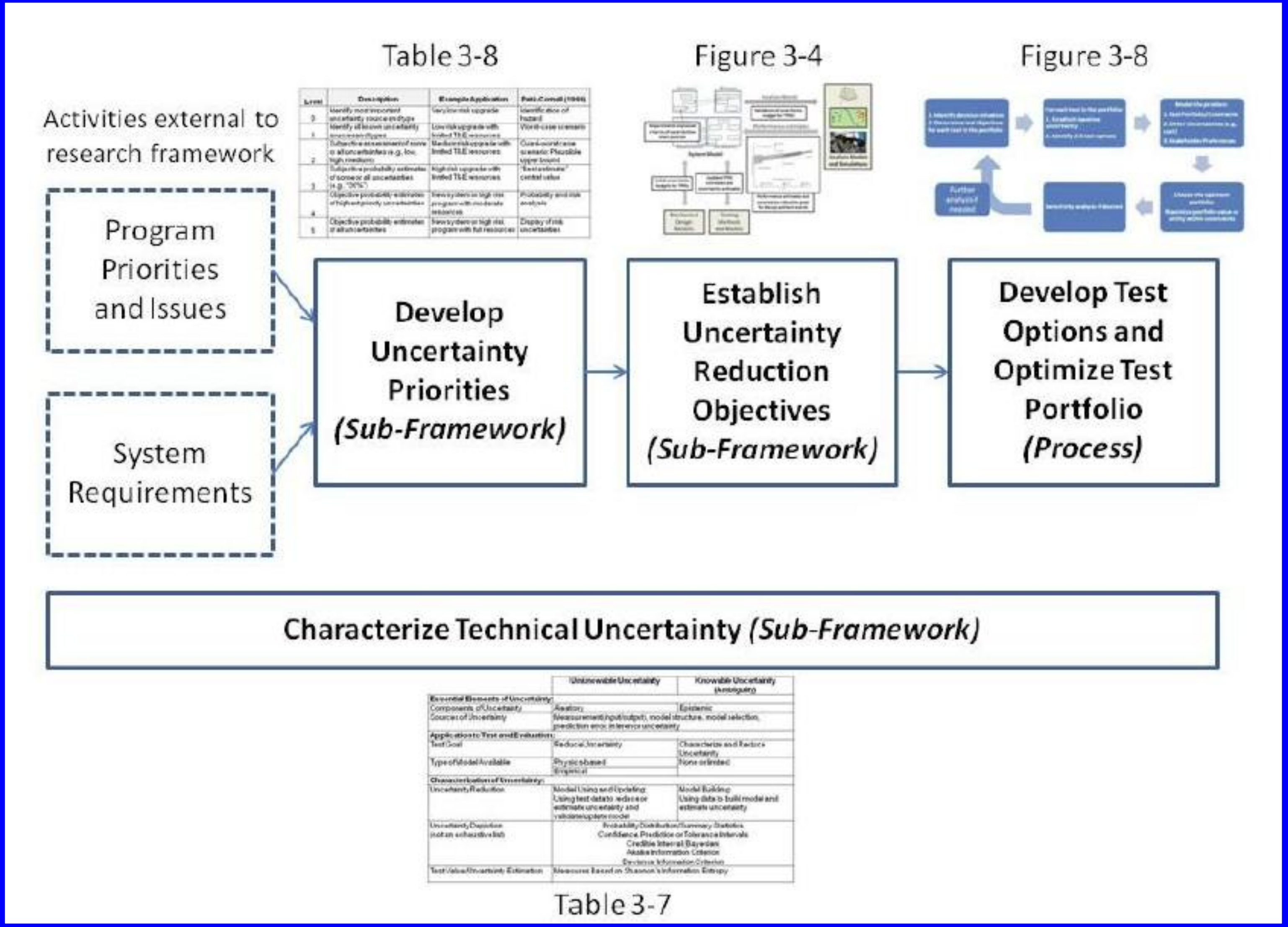


Table 3-8

Figure 3-4

Figure 3-8

Activities external to research framework

Program Priorities and Issues

System Requirements

Develop Uncertainty Priorities *(Sub-Framework)*

Establish Uncertainty Reduction Objectives *(Sub-Framework)*

Develop Test Options and Optimize Test Portfolio *(Process)*

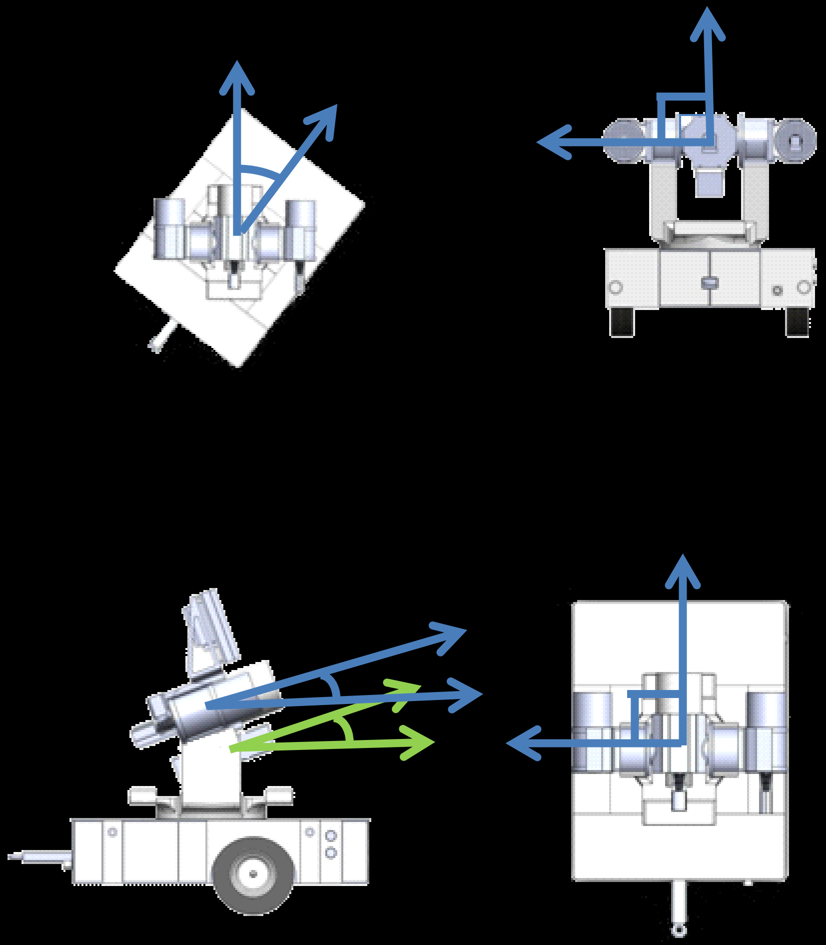
Characterize Technical Uncertainty *(Sub-Framework)*

Table 3-7

**From "Test and Evaluation Resource Allocation Using Uncertainty Reduction as a Measure of Test Value," E. A. Bjorkman, 2012*

Systematic Error Sources

- Zero Offset
- Collimation
- Tilt
- Vertical Deflection
- Droop
- Non-orthogonality
- Parallax
- Refraction



Model Assumptions

- 2D model
  - Elevation angle assumed constant, zero degrees
  - Target follows straight path
- CKEM target visible and tracked throughout trajectory
  - 1.5m length, solid-fuel rocket
  - Velocity: 6.5+ Mach