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Title: Real-time Condition Assessment of RAPTOR Telescope Systems

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Tokyo, Japan,
Nov. 30 – Dec. 2, 2010

Real-time Condition Assessment of RAPTOR Telescope Systems

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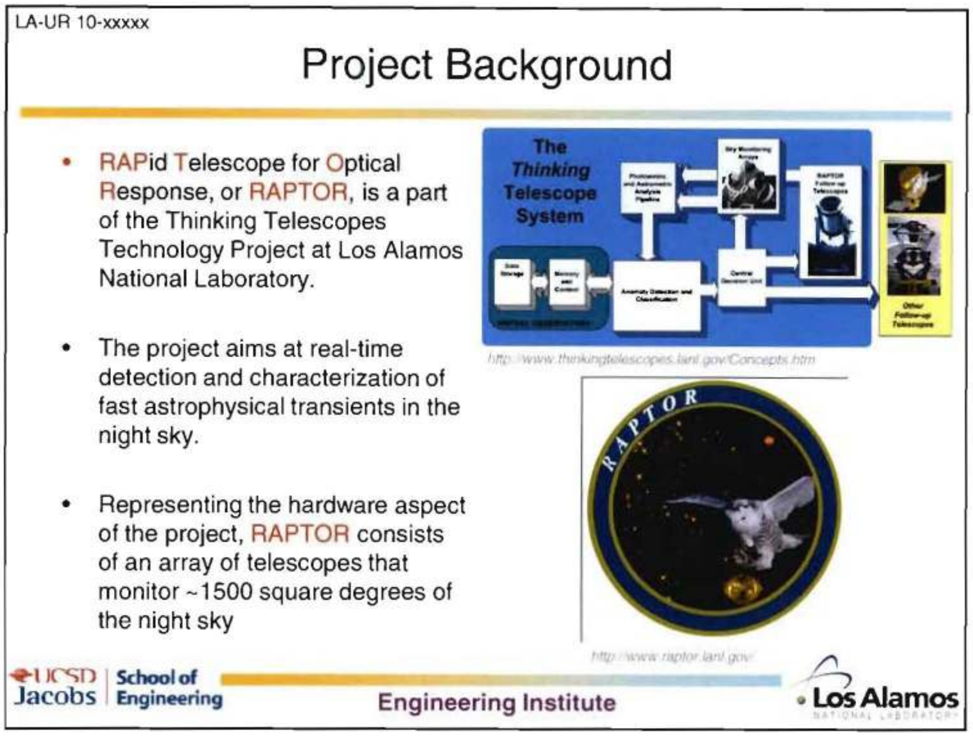
Abstract

- The RAPid Telescopes for Optical Response (RAPTOR) observatory network consists of several robotic astronomical telescopes primarily designed to search for astrophysical transients called a gamma-ray bursts (GRBs). Although intrinsically bright, GRBs are difficult to detect because of their short duration. Typically, they are first observed by satellites that then relay the coordinates of the GRB to a ground station which, in turn, distributes the coordinates over the internet so that ground based observers can perform follow-up observations. Typically the ground based observations begin after the GRB has ended and only residual emission (the "afterglow") is left. However, if the satellite relays the GRB coordinates quickly enough, a "fast" robotic telescope on the ground may be able to catch the GRB in progress. The RAPTOR telescope system is one of only a few in the world to have accomplished this feat. In order to achieve these results, the RAPTOR telescopes must operate autonomously at a high duty-cycle and in peak operating condition. Currently the telescopes are maintained in an *ad hoc* manner, often in a run-to-failure mode. The RAPTOR project could benefit greatly from a structural health monitoring (SHM) system, especially as more complex units are added to the suite of telescopes.

- This paper will summarize preliminary results from an SHM study performed on one of the RAPTOR telescopes. Damage scenarios that are of concern and that have been previously observed are first summarized. Then a specific study of damage to the telescope drive mechanism is presented where the data acquisition system is first described. Next, damage detection algorithms are developed with LANL's new publically available software SHMTools and the results of this process are discussed in detail. The paper will conclude with a summary of future planned refinements of the RAPTOR SHM system.



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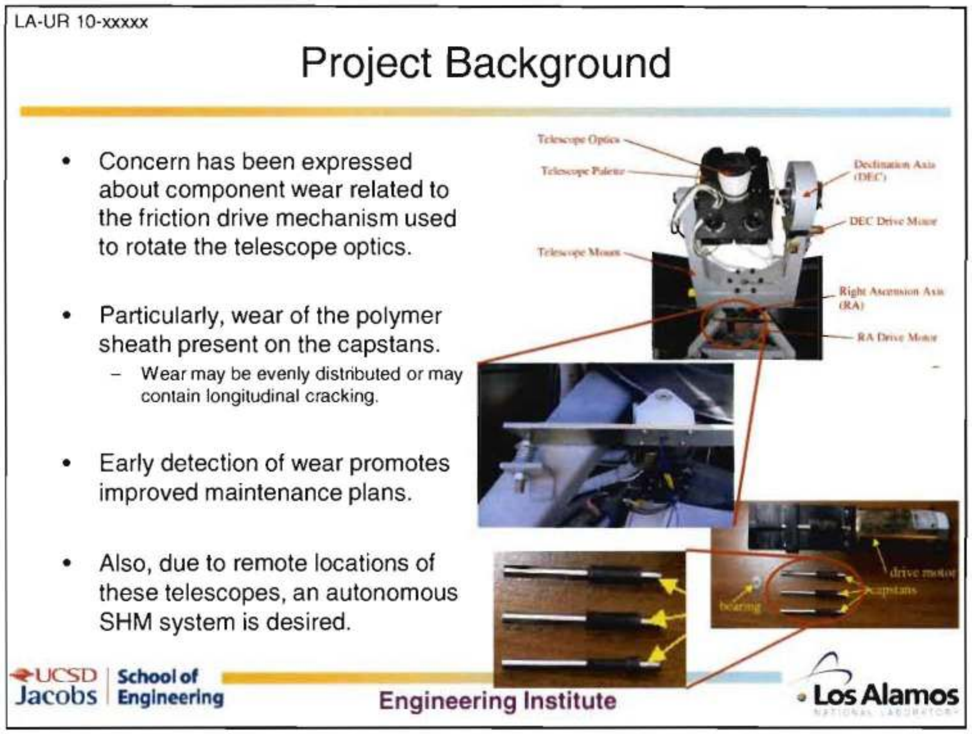
Project Background

- RAPid Telescope for Optical Response, or RAPTOR, is a part of the Thinking Telescopes Technology Project at Los Alamos National Laboratory.
- The project aims at real-time detection and characterization of fast astrophysical transients in the night sky.
- Representing the hardware aspect of the project, RAPTOR consists of an array of telescopes that monitor ~1500 square degrees of the night sky

http://www.thinkingtelescopes.lanl.gov/Concepts.htm

http://www.raptor.lanl.gov/



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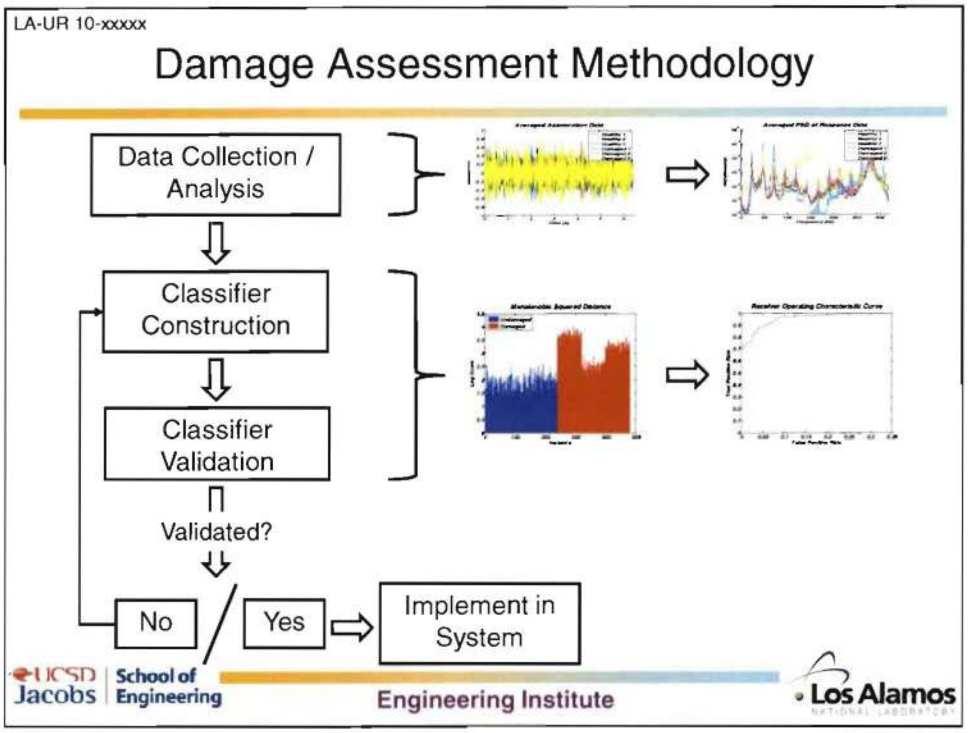
Project Background

- Concern has been expressed about component wear related to the friction drive mechanism used to rotate the telescope optics.
- Particularly, wear of the polymer sheath present on the capstans.
  - Wear may be evenly distributed or may contain longitudinal cracking.
- Early detection of wear promotes improved maintenance plans.
- Also, due to remote locations of these telescopes, an autonomous SHM system is desired.



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Damage Assessment Methodology

Data Collection / Analysis

Classifier Construction

Classifier Validation

Validated?

No / Yes

Implement in System

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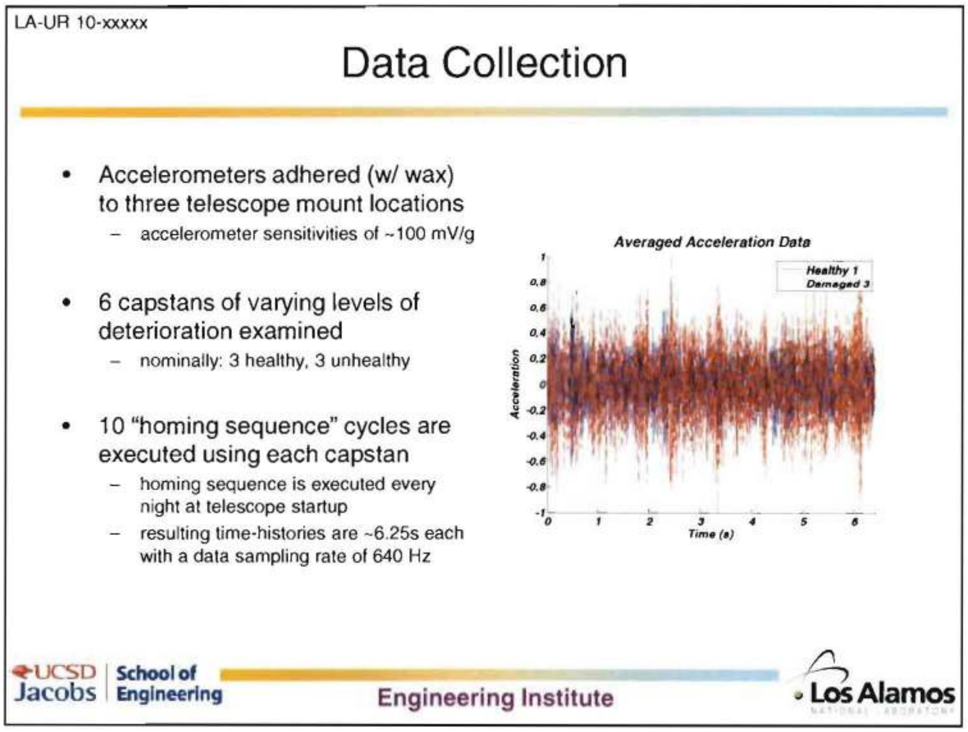

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Data Collection

- Accelerometers adhered (w/ wax) to three telescope mount locations
  - accelerometer sensitivities of ~100 mV/g
- 6 capstans of varying levels of deterioration examined
  - nominally: 3 healthy, 3 unhealthy
- 10 "homing sequence" cycles are executed using each capstan
  - homing sequence is executed every night at telescope startup
  - resulting time-histories are ~6.25s each with a data sampling rate of 640 Hz

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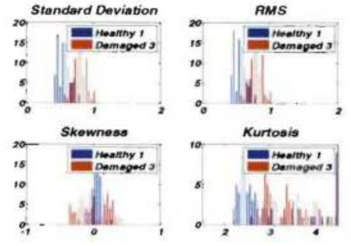
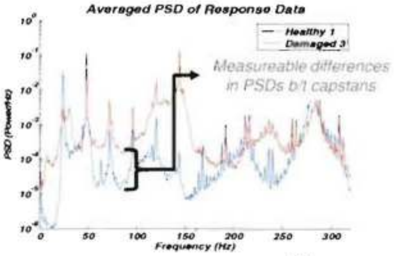
Data Analysis

- Individual time-histories divided into equal-sized records in order to simulate data replicates
  - Record length = 512 samples
- Statistical features of time-history replicates computed
  - Standard Deviation
  - Root-mean-square (RMS)
  - Skewness
  - Kurtosis
- Power spectral densities (PSDs) computed from each time history, and averaged across each capstan condition.





Classifier Construction

- Damage classifier based upon *a priori* knowledge of baseline system condition.
- Typically, this baseline condition is "learned"
  - *e.g.*, coefficients of a polynomial may be fit to represent the some data.
- For this task, a software system developed at the LANL/UCSD Engineering Institute is employed:
  - SHMTools: a suite of structural health monitoring tools;
  - mFUSE: a graphical user interface serving as a MATLAB function sequencer

http://institute.lanl.gov/ei/

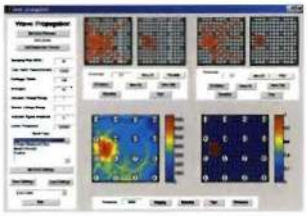
http://institute.lanl.gov/ei/software-and-data/SHMTools/

SHMTools and mFUSE

Eric Flynn, Dustin Harvey, Samori Kuofu, Stuart Taylor, Elói Figueiredo

- Standardized
  - Naming
  - Documentation
  - Function arguments
  - Experimental data
  - Usage examples
- Easy to Use
  - Modular
  - Extensive Documentation
  - Example Usage
- Expandable
  - Open Source
  - Flexible Structure
- Hardware Embeddable
  - Efficient
  - Converts to Compilable Code
- Research Orientated
  - Freely available
  - Open source
  - Useful to the SHM community
  - Serves as reference material
  - Cites research literature

Download from http://institutes.lanl.gov/ei



Extensive Function Library

User Input Controls

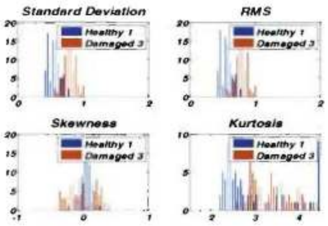
Script Preview

Process Export

Classifier Construction

Feature Extraction

- Time-history replicates from all three channels are employed to construct damage classifier.
- As before, the high dimensionality of the time-history replicates, is condensed using statistical features:

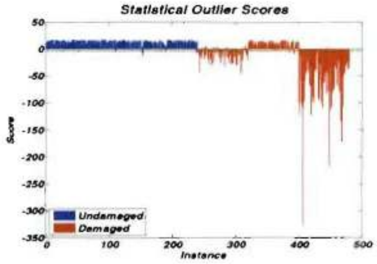


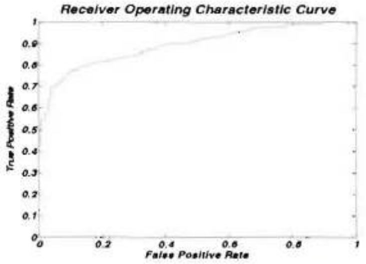
Classifier Construction

- In this case, a semi-parametric Gaussian mixture model (GMM) was employed as a more statistics-based classifier.
- Aims to "learn" a mixture of Gaussians which describe the clustering nature of the feature vector (*i.e.* the statistical features extracted from the time-history replicates).
- For the present study, a single Gaussian is learned.

Classifier Validation

- A clear difference exists between the undamaged capstans and the 1st and 3rd damaged capstans.
- As exhibited by the plot of the outlier scores, a reasonable threshold exists between the undamaged and damage conditions.
- However, as with the previous classifier, the 2nd damaged capstan exhibits scores more in line with those associated with the undamaged capstans.





Alternate Classifier Construction

Feature Extraction

- Time-history replicates from one channel (*i.e.* one accel.) are employed to construct damage classifier.
- Given high dimensionality of time-history replicates, an autoregressive (AR) model is constructed, given as:

$$X_t = \sum_{j=1}^{p} \alpha_j x_{t-j} + \varepsilon_t$$

where α_j are the parameters of the AR model of order, p , and ε_t is assumed to be white noise.

- A 30th-order AR model is constructed, with associated parameters used as features for "training" and "scoring" damage classifier.

Classifier Construction

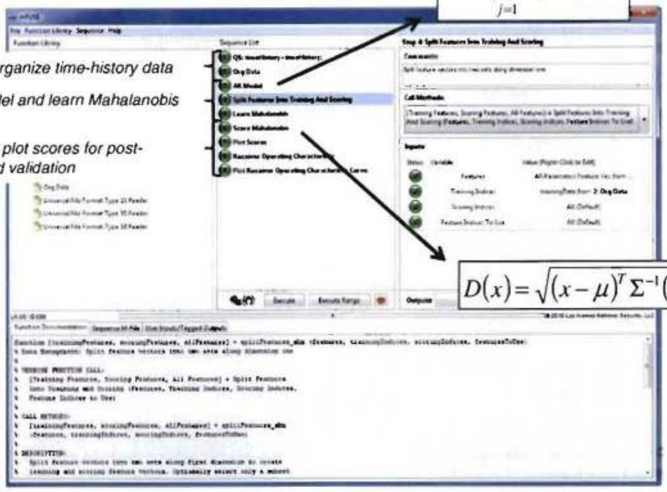
- With *a priori* knowledge of the healthy (*i.e.* baseline) conditions, the mean vector, μ, and covariance matrix, Σ, of the AR parameters associated with these conditions are computed.
- The Mahalanobis distance (given below) may now be employed as a means of detecting outliers:

$$D(x) = \sqrt{(x-\mu)^T \Sigma^{-1} (x-\mu)}$$

where x contains AR parameters formed from a potentially damaged condition.

mFUSE Function Sequence

$$X_t = \sum_{j=1}^{p} \alpha_j x_{t-j} + \varepsilon_t$$

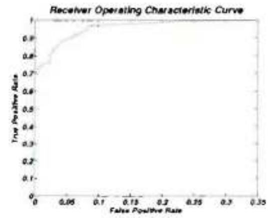


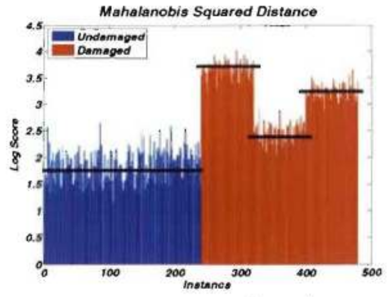
- *read in and organize time-history data*
- *build AR model and learn Mahalanobis distance*
- *compute and plot scores for post-processing and validation*

$$D(x) = \sqrt{(x-\mu)^T \Sigma^{-1} (x-\mu)}$$

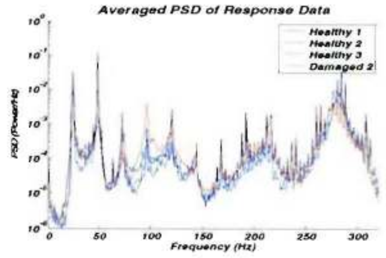
Alternate Classifier Validation

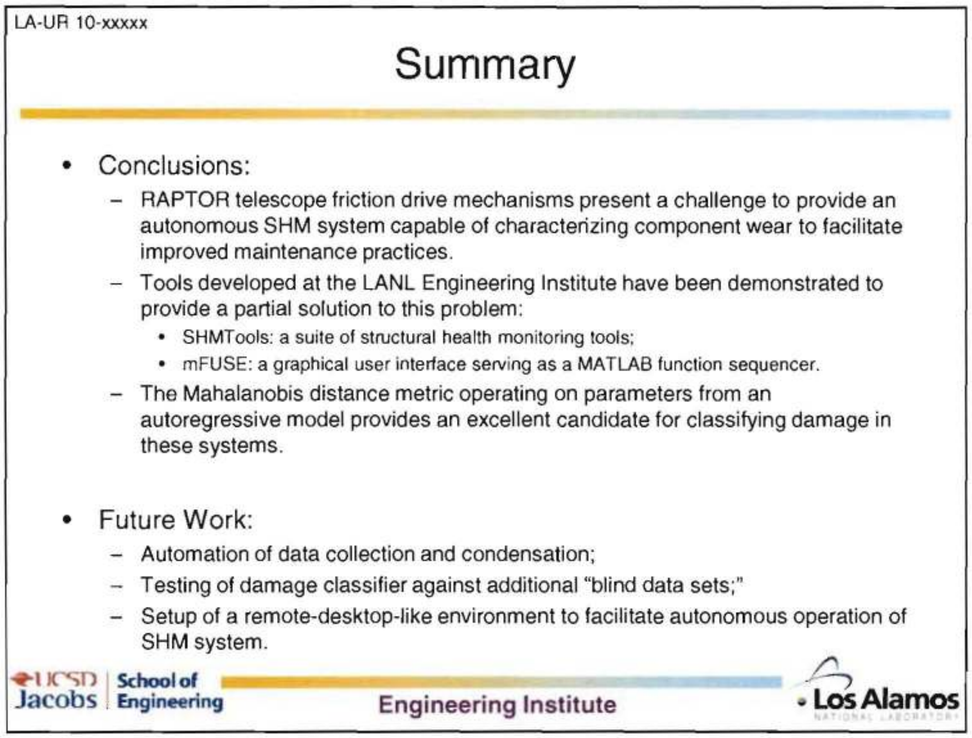
- Threshold for Mahalanobis distance may be established which detects, with <u>reasonable accuracy</u>, the presence of damage.





The lower average score associated with the 2nd "damaged" capstan is consistent w/ observations in that a the time-histories from this capstan exhibited a similar PSD as compared to the healthy capstans.





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Summary

- Conclusions:
  - RAPTOR telescope friction drive mechanisms present a challenge to provide an autonomous SHM system capable of characterizing component wear to facilitate improved maintenance practices.
  - Tools developed at the LANL Engineering Institute have been demonstrated to provide a partial solution to this problem:
    - SHMTools: a suite of structural health monitoring tools;
    - mFUSE: a graphical user interface serving as a MATLAB function sequencer.
  - The Mahalanobis distance metric operating on parameters from an autoregressive model provides an excellent candidate for classifying damage in these systems.

- Future Work:
  - Automation of data collection and condensation;
  - Testing of damage classifier against additional "blind data sets;"
  - Setup of a remote-desktop-like environment to facilitate autonomous operation of SHM system.

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