A Day in the Life of Groundhog

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Robotic Subterranean Mapping

MRD Fall 2002

The Robotics Institute
Carnegie Mellon University

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Introduction Day 1

- Goals of MRD
  - Mix with the events of our time
  - Change the world
  - Develop the technologies, Robots, and Leaders of the Future
- Goals this year
  - Motivated by Quecreek
  - Build mine worthy robots
  - Map abandoned mines

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Declaration of Purpose Day 3

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Groundhog Day 12

- Class commits to Quecreek "Quick-Look"
- Quecreek Expected Conditions
  - 4' high by 6' wide by 4' long breach between the mines
  - Breach 1' above mine floor
  - Wet, muddy conditions

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Groundhog Day 12

- Chassis
  - 2 Honda ATV front-ends welded together
  - 4 wheel drive & steer
  - Components available by cannibalizing an earlier robot

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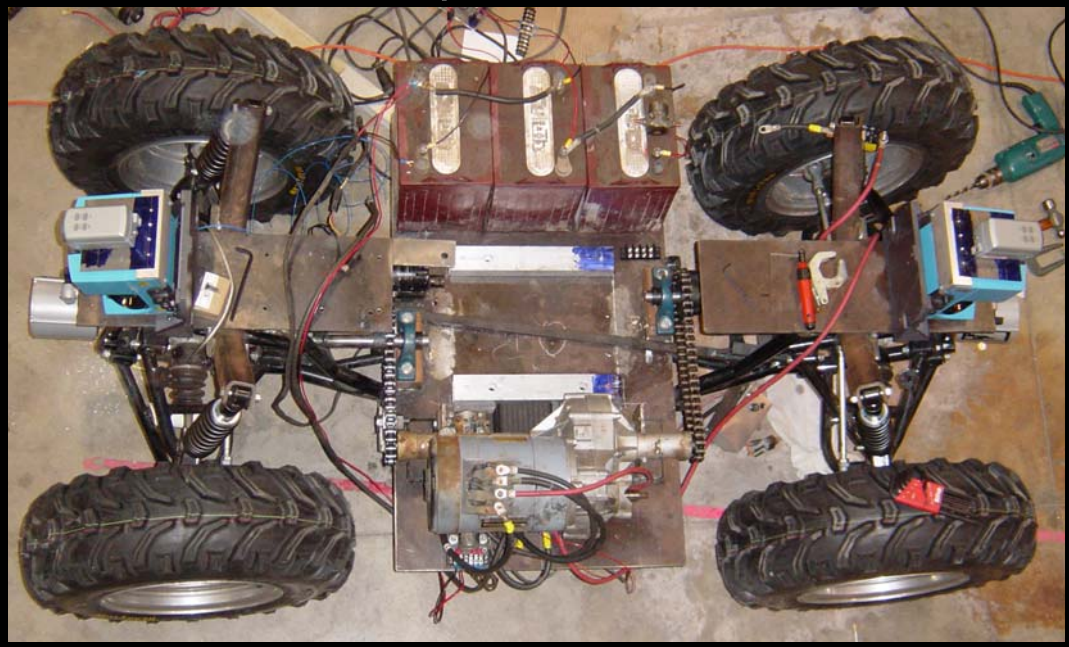
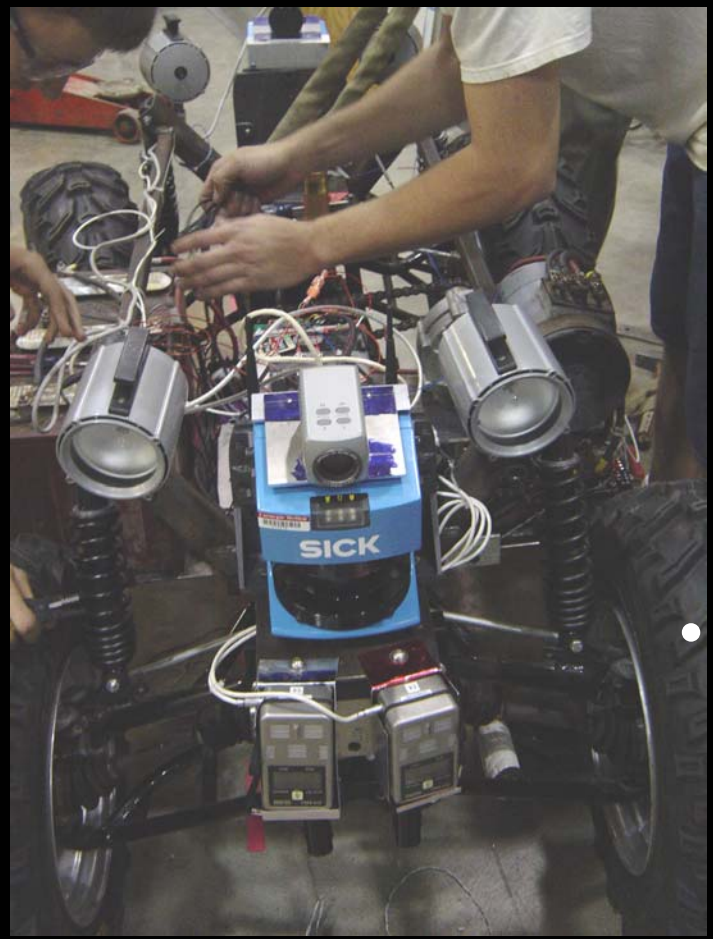
Groundhog Day 20-21

- “Chassis in a Day” (or two)
- “Design in a Day”
  - Linked Ackerman steering – 8’ turning radius
  - Golf cart drive train ~ 6 mph max
  - Originally designed to carry Quantapoint laser scanner



Groundhog Day 30



- Test at Bruceton Research Mine
  - Fully electric vehicle
  - Button box control
  - Wireless communications and laser range tested

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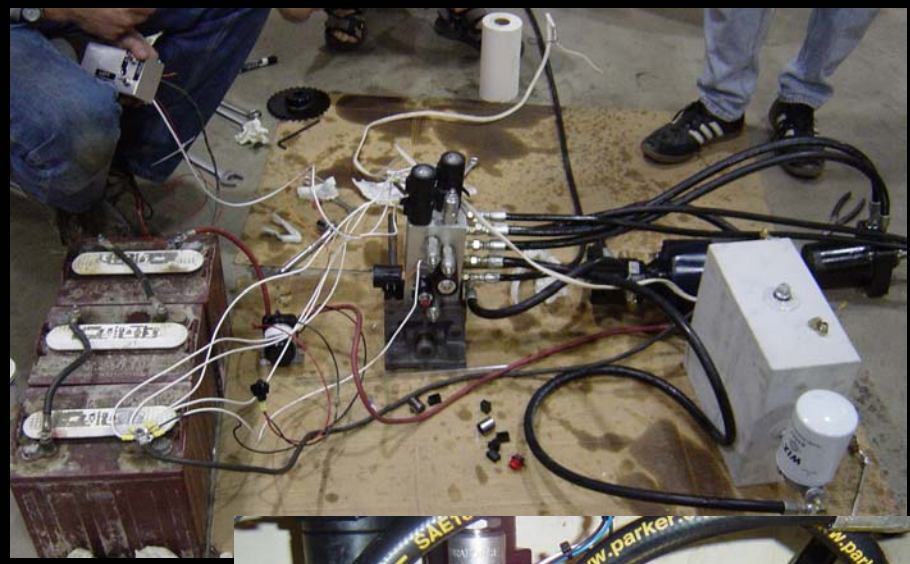
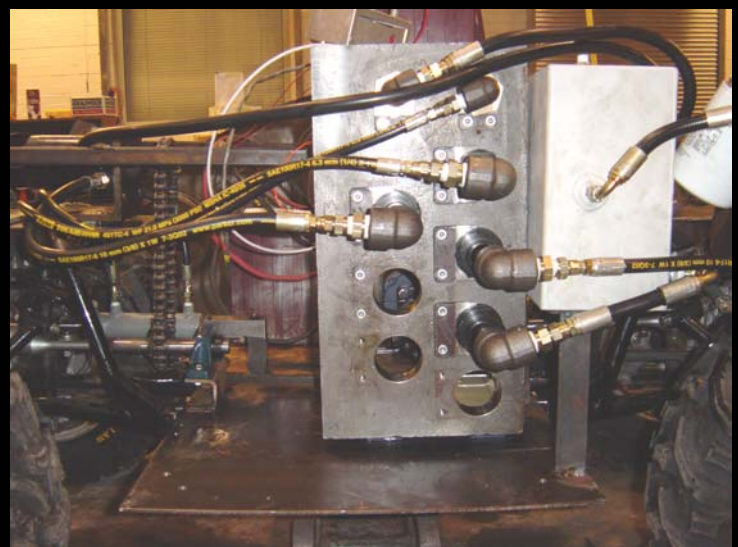
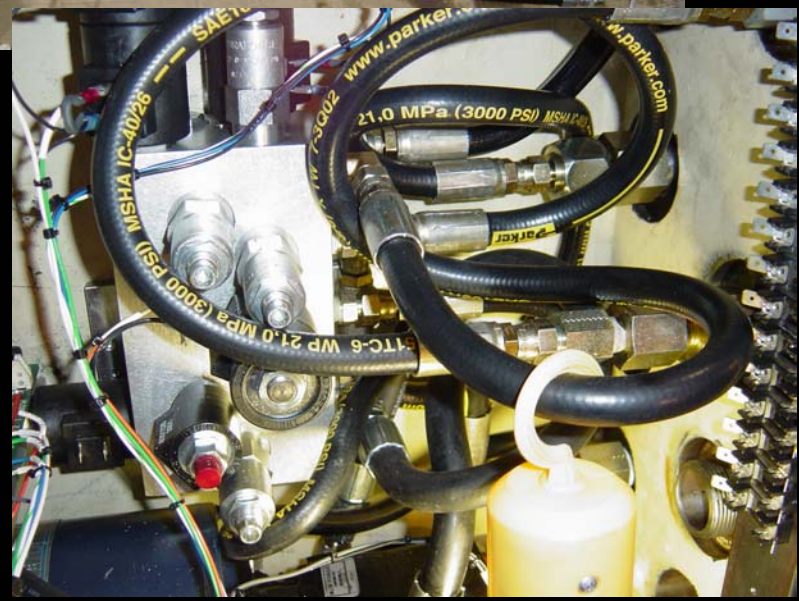
Groundhog Day 36

- Access denied due to safety concerns
- Retrofit to Hydraulics and explosion proof enclosure is undertaken







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Groundhog Day 43

- Groundhog total mass roughly doubles, requiring additional structural support
- Electronics and computer control are integrated into the explosion-proof box

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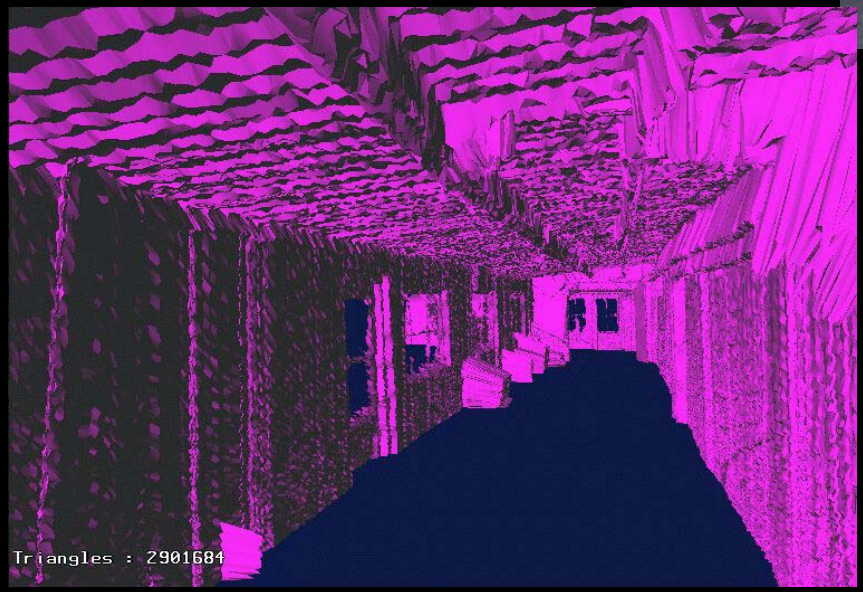
Groundhog Day 54

- CMU Highbay Trials
  - Surmounting Obstacles
  - Fiber Tether
  - Wireless Slip-Ring



First Successful 2D and 3D mapmaking

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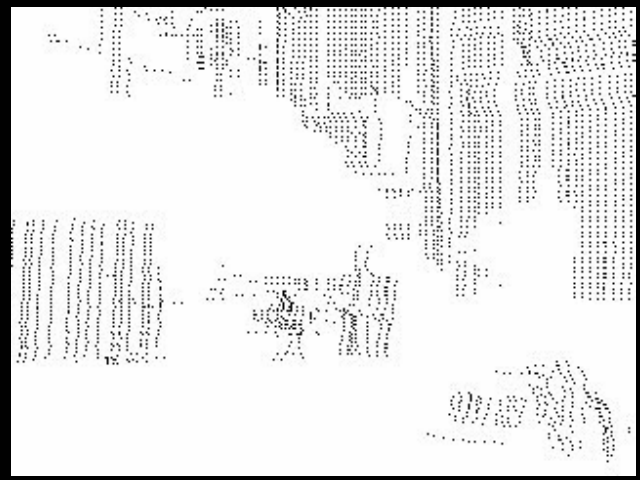
Groundhog Day 54

The Highbay



X – You Are Here

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Groundhog Day 63

- Florence Mine, Burgettstown, PA
  - First robotic mapping of an abandoned mine

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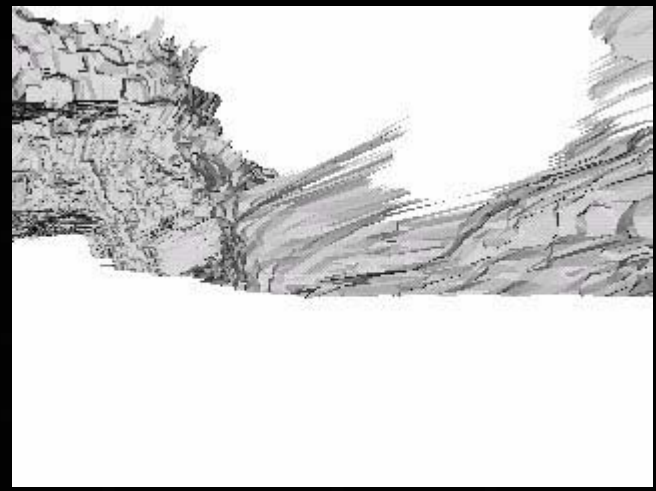
Groundhog Day 63



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Groundhog Day 63

The Limiting Factors

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Groundhog Day 65

- Live satellite feed to MSHA Symposium

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Groundhog Day 65

- That evening on the news…

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Groundhog Day 93

- Extensive Mapping of Bruceton Mine
  - Robot Range and Endurance
    - >1 mile traverse in 3.5 hrs (28.5 ft/min)
  - Largest data set to date.
    - 300+ MB of laser data

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Groundhog Day 93

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Groundhog Day 106

- We can take a couple of questions now…

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THE FERRET

Borehole deployable laser scanner for 3D mapping, map verification, and void analysis

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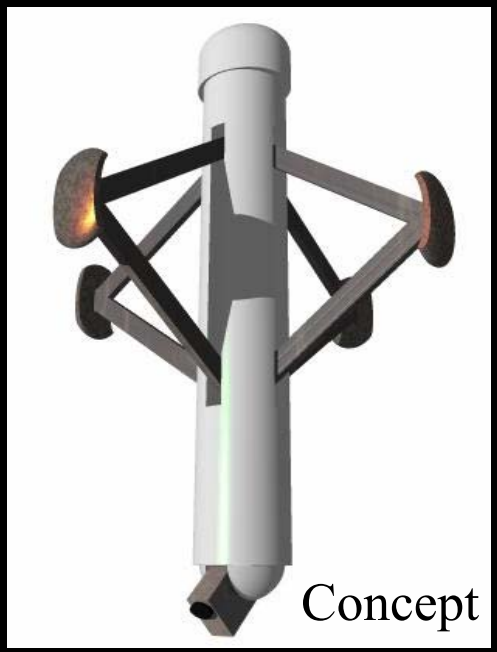
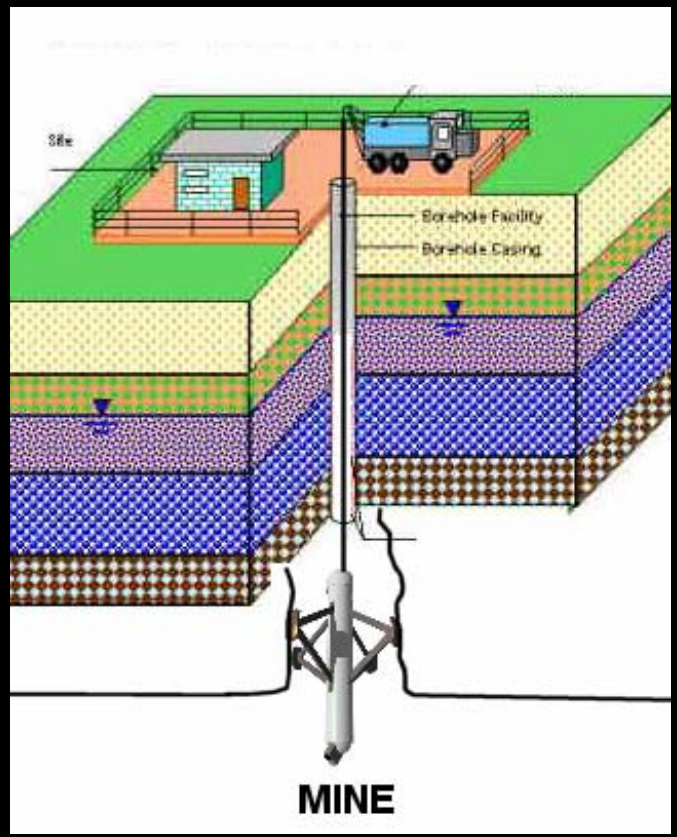
Ferret: The General Concept

- Laser Range Finder
- PTU
- Fit in 6” Borehole





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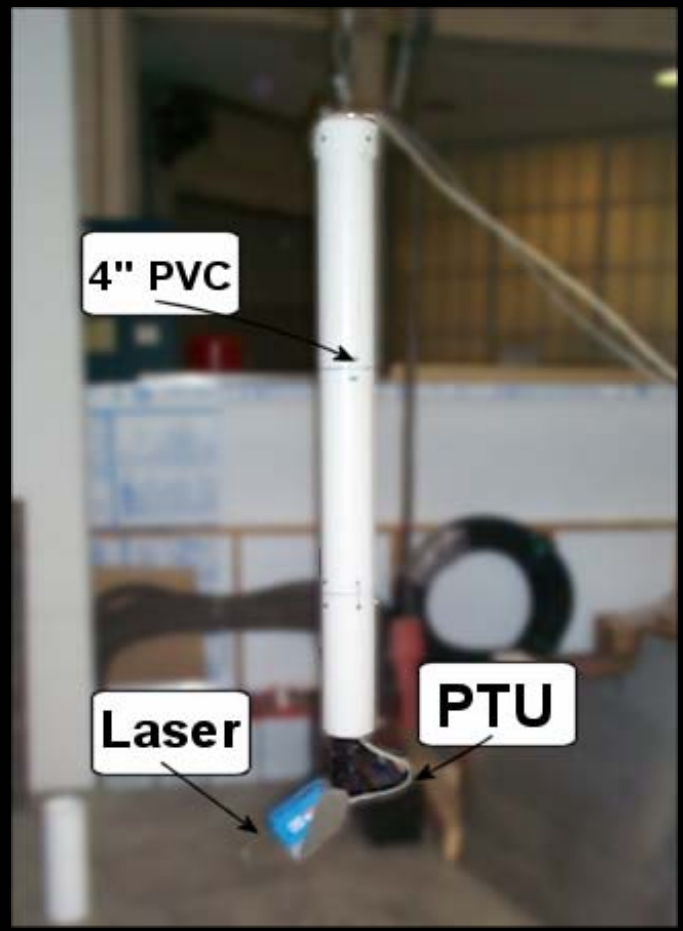
Ferret I

- Point Laser Range Finder
- PTU
- 4” PVC encasing
- Dual Serial Communication
- Command Driven Interface



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Experimentation

- Denied Access
- Limited Laser Range
- Mellon Institute

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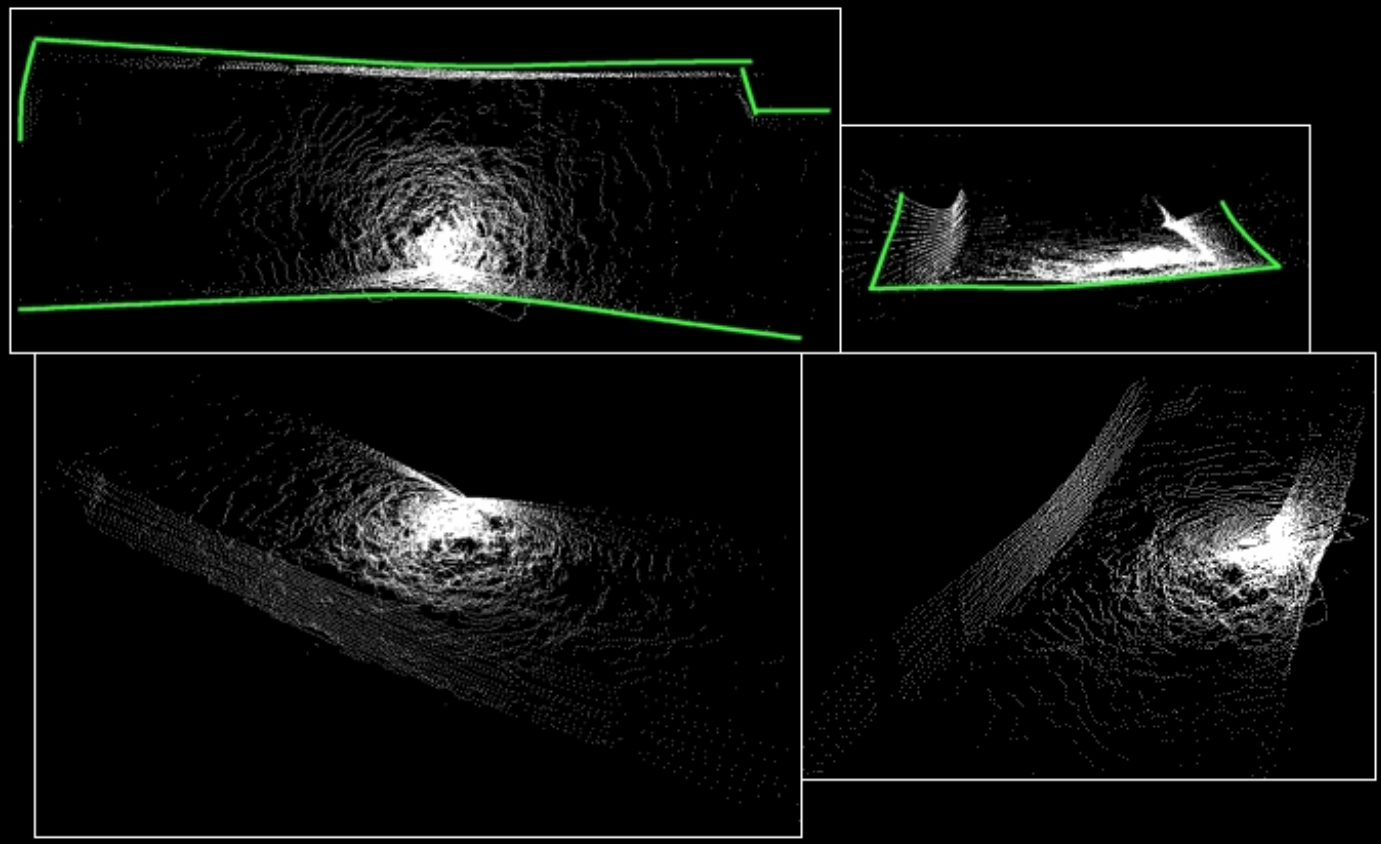
Mellon Institute Results



Mellon Institute Void

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The End of Ferret?

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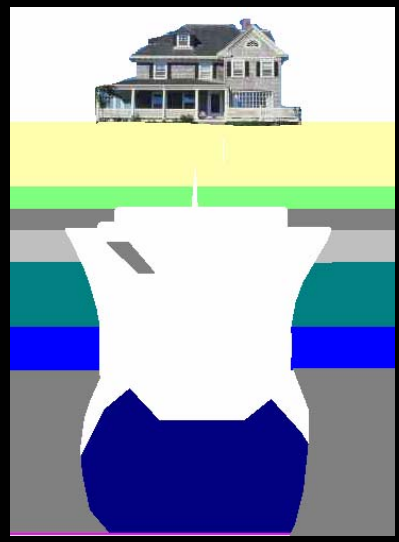
Problems in Kansas City

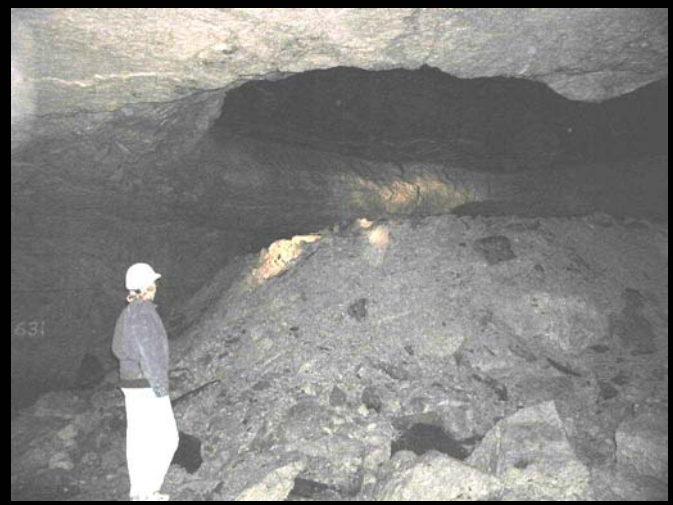
- Kansas City Limestone Mines
- Weak Ceiling Integrity results in Domeouts
- Prohibit Development



Morning temblor makes appearance in KCK

Mild quake strong enough to cause damage

Rare event leads to dozens of phone calls



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How do they verify backfill?

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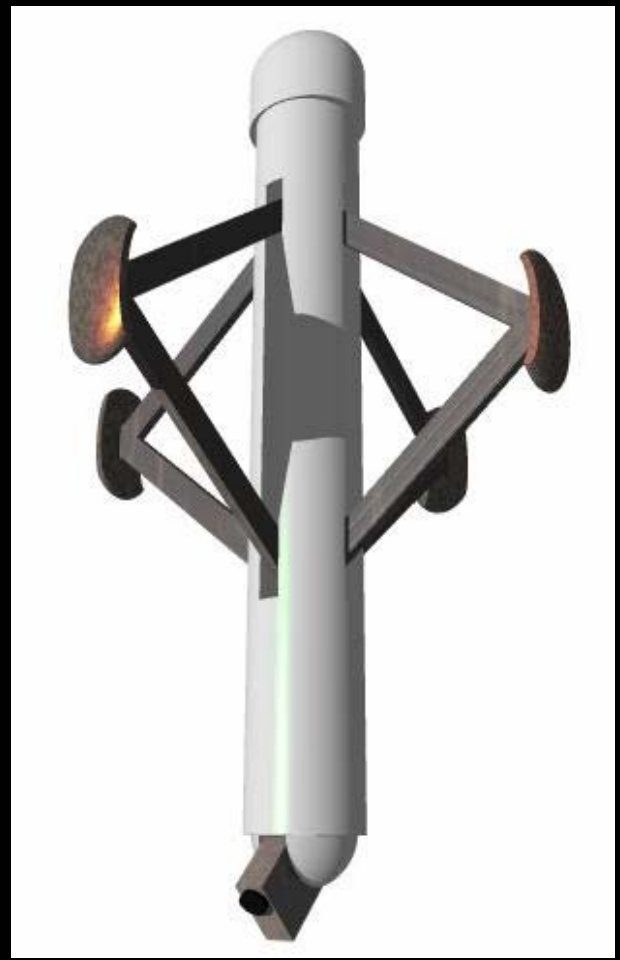
Ferret II Hardware Design

- Long Range – Low Reflectivity Laser
- Pan & Tilt Unit
- Embedded Microprocessor
- Magnetic Compass
- Inclination Sensors
- Video Camera & Lights
- Proximity Sensors
- Deployment Device



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Ferret II Software Design

- Breach Recognition
- Scanning Control
- Data Acquisition
- Data Processing
  - Filtering
  - 3D realization
  - Dimension and Volumetric Analysis
- Map Correlation
- User Control Interface

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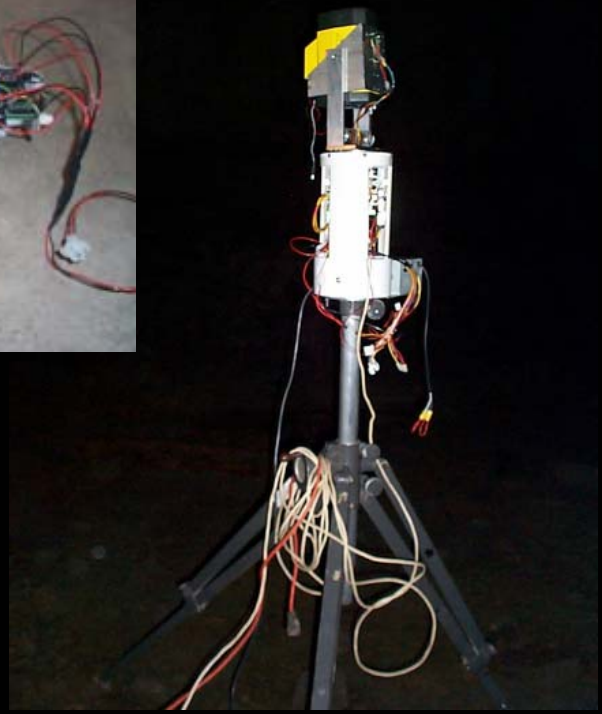
Ferret II

Ferret
Components



Ferret In Testing
Configuration

Ferret Before 1st Deployment

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Ferret II in Kansas City

- Deployed down 3 boreholes
- Borehole depth typically 150 ft
- Performed 9hrs of operation in 24 hrs
- Operated 4 hrs on single battery charge

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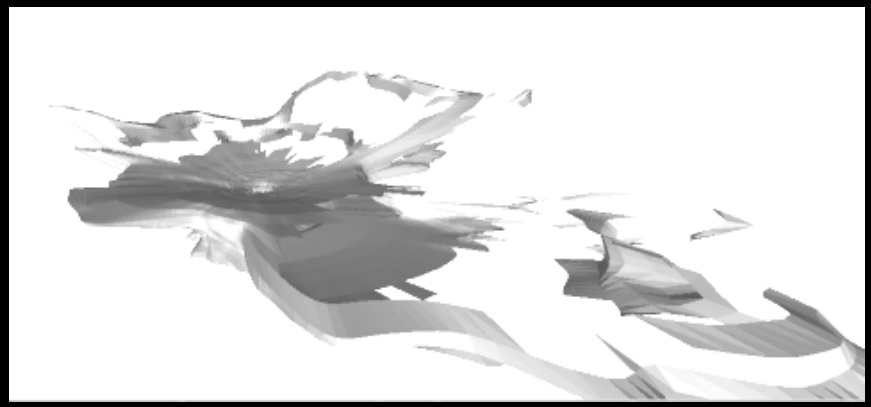
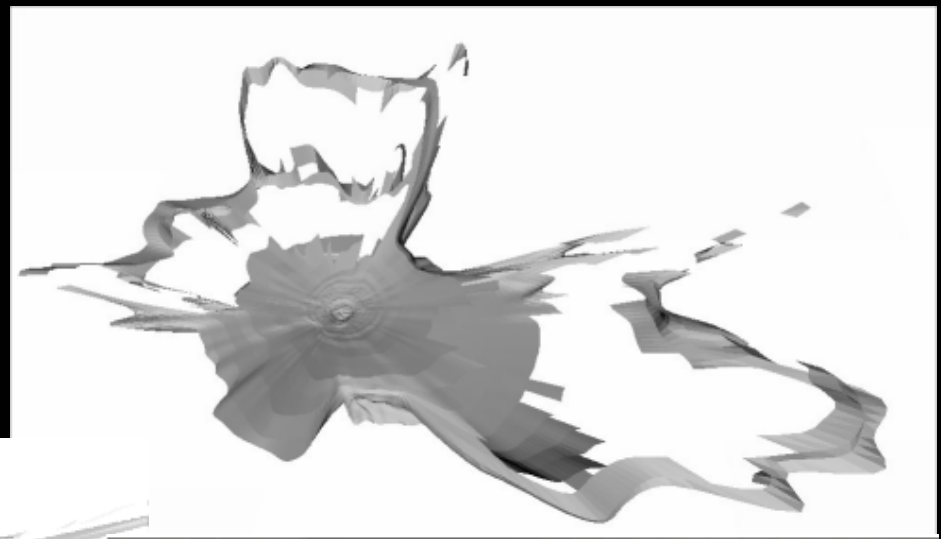
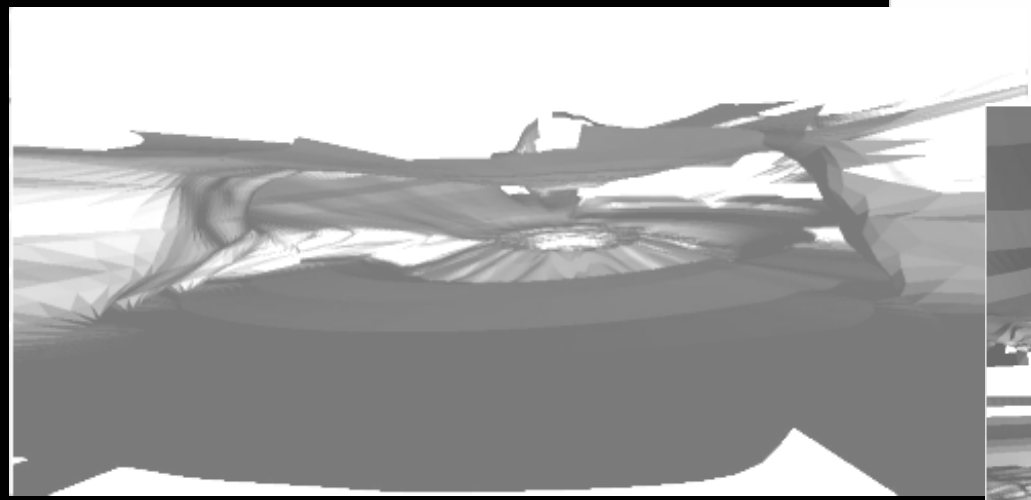
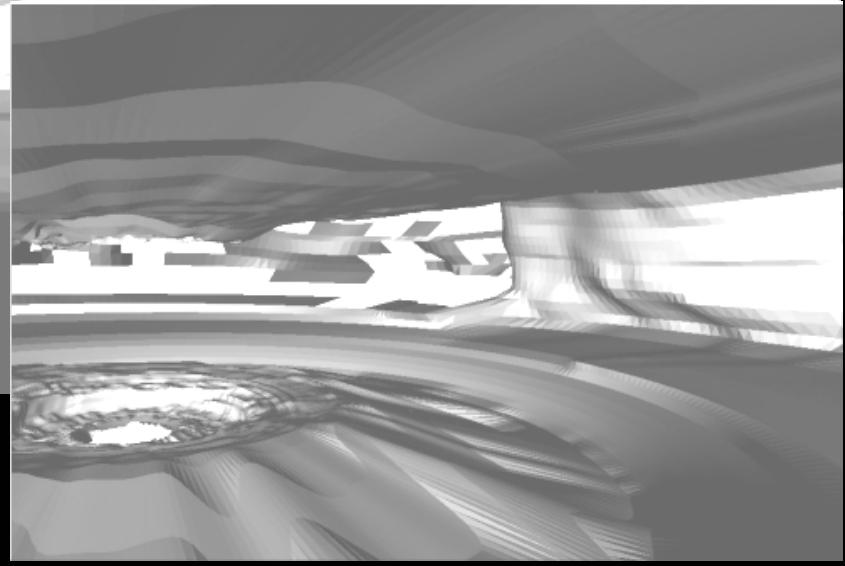
Kansas City Preliminary Results









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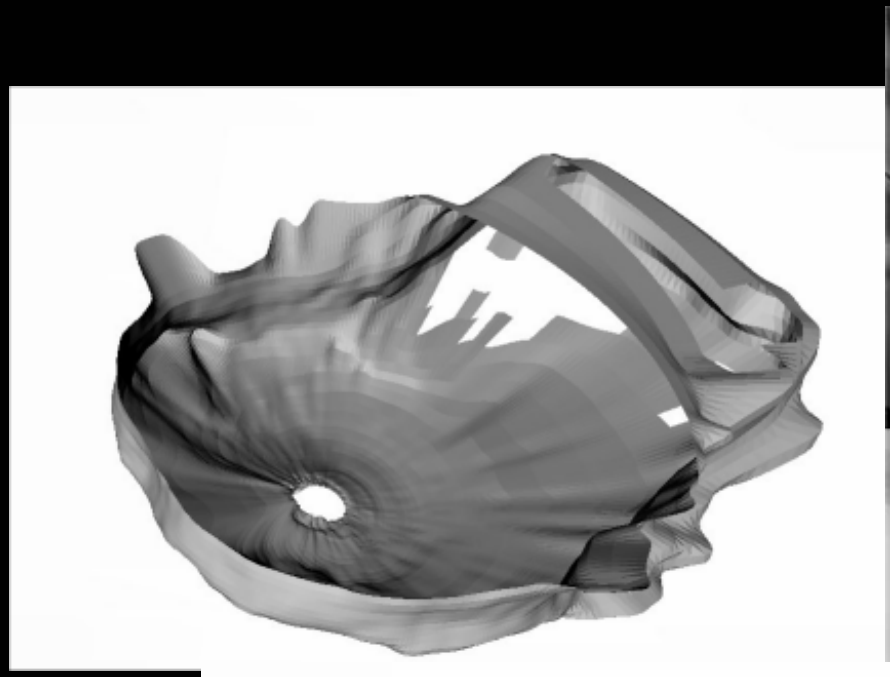
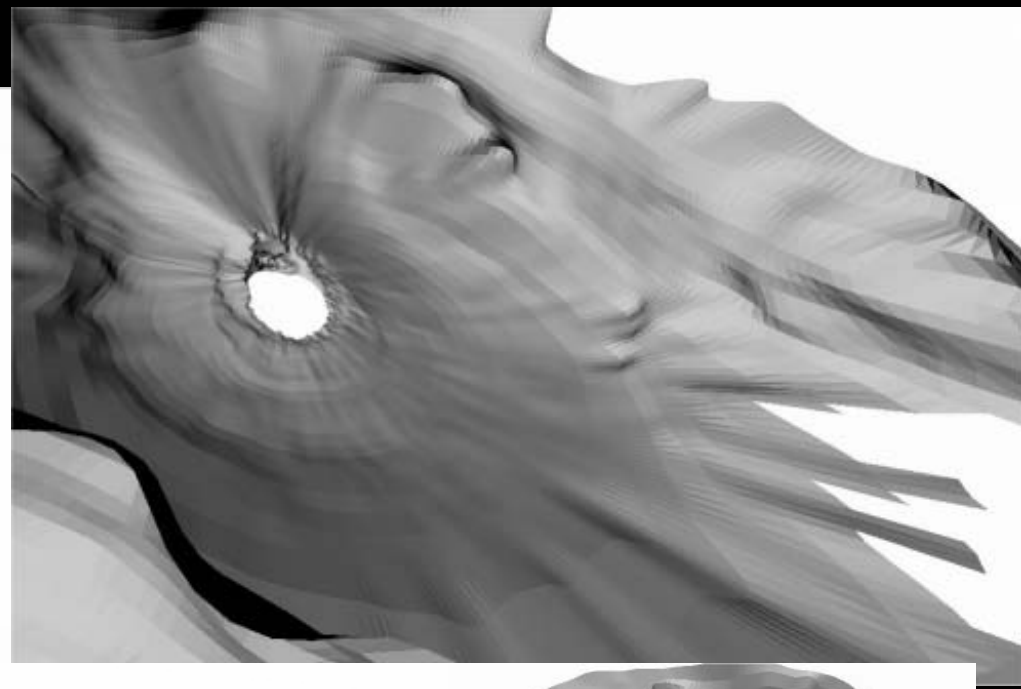
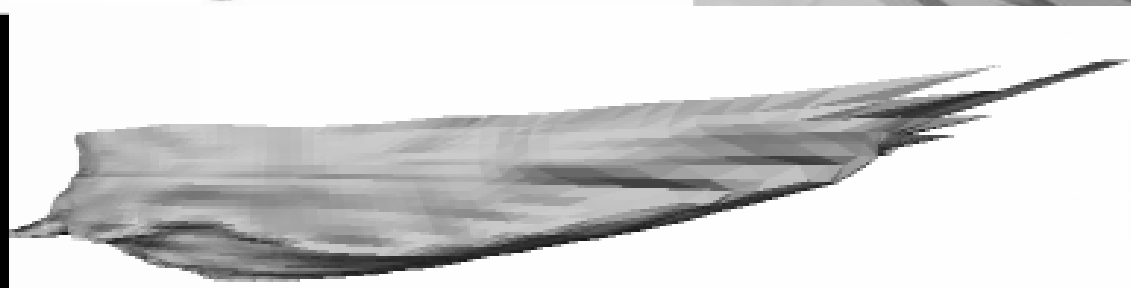
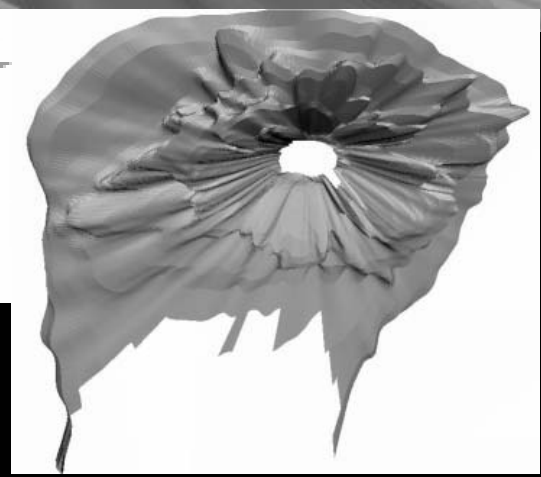
Hole M8 - Water/Air Mix

Kansas City Preliminary Results









Hole M5 - Domeout

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Visual Confirmation

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That’s Not All For Ferret, But…

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Ferret Questions?

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Business

- Idan will talk about the business plan…

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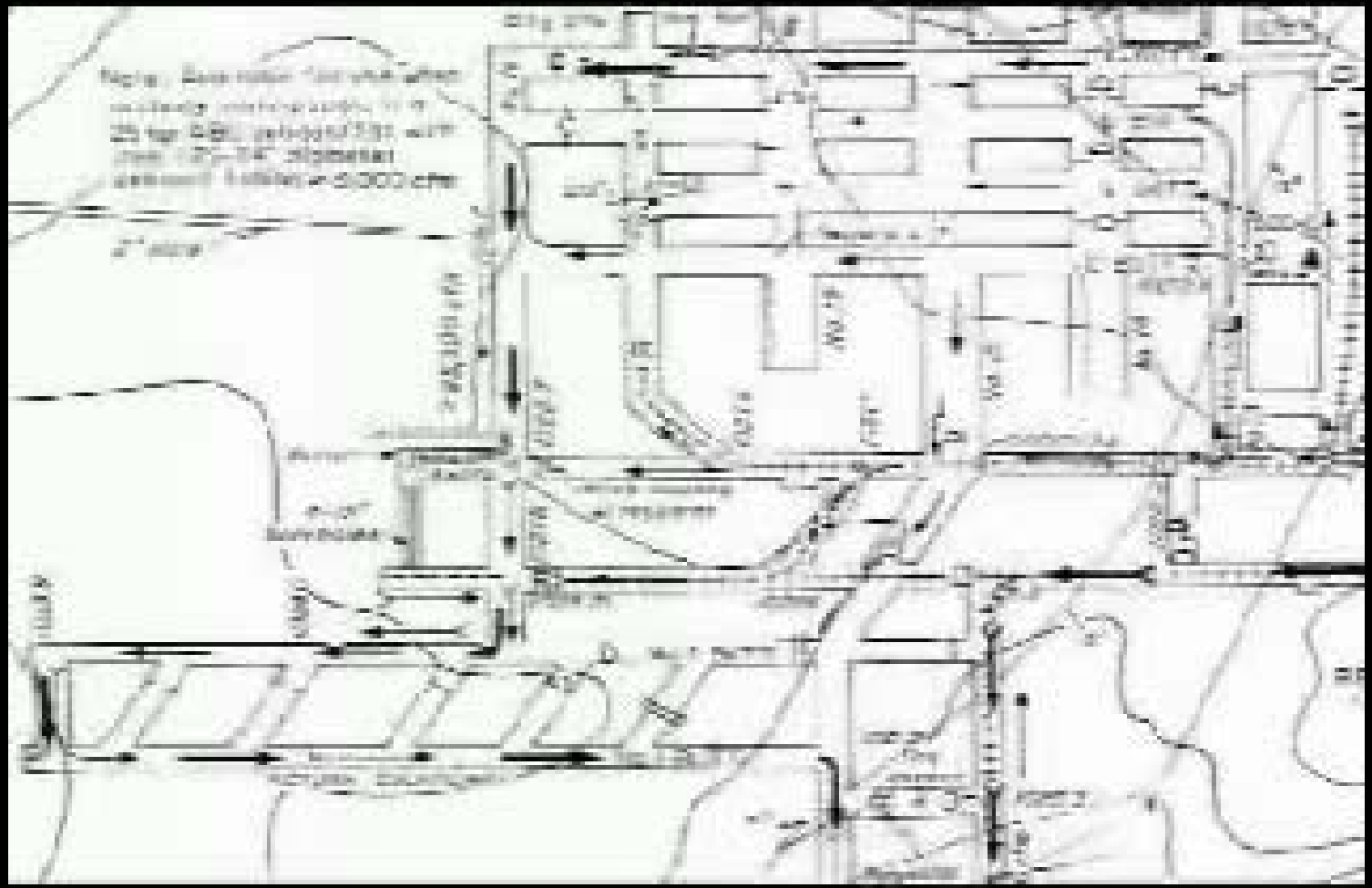
Registering A Map



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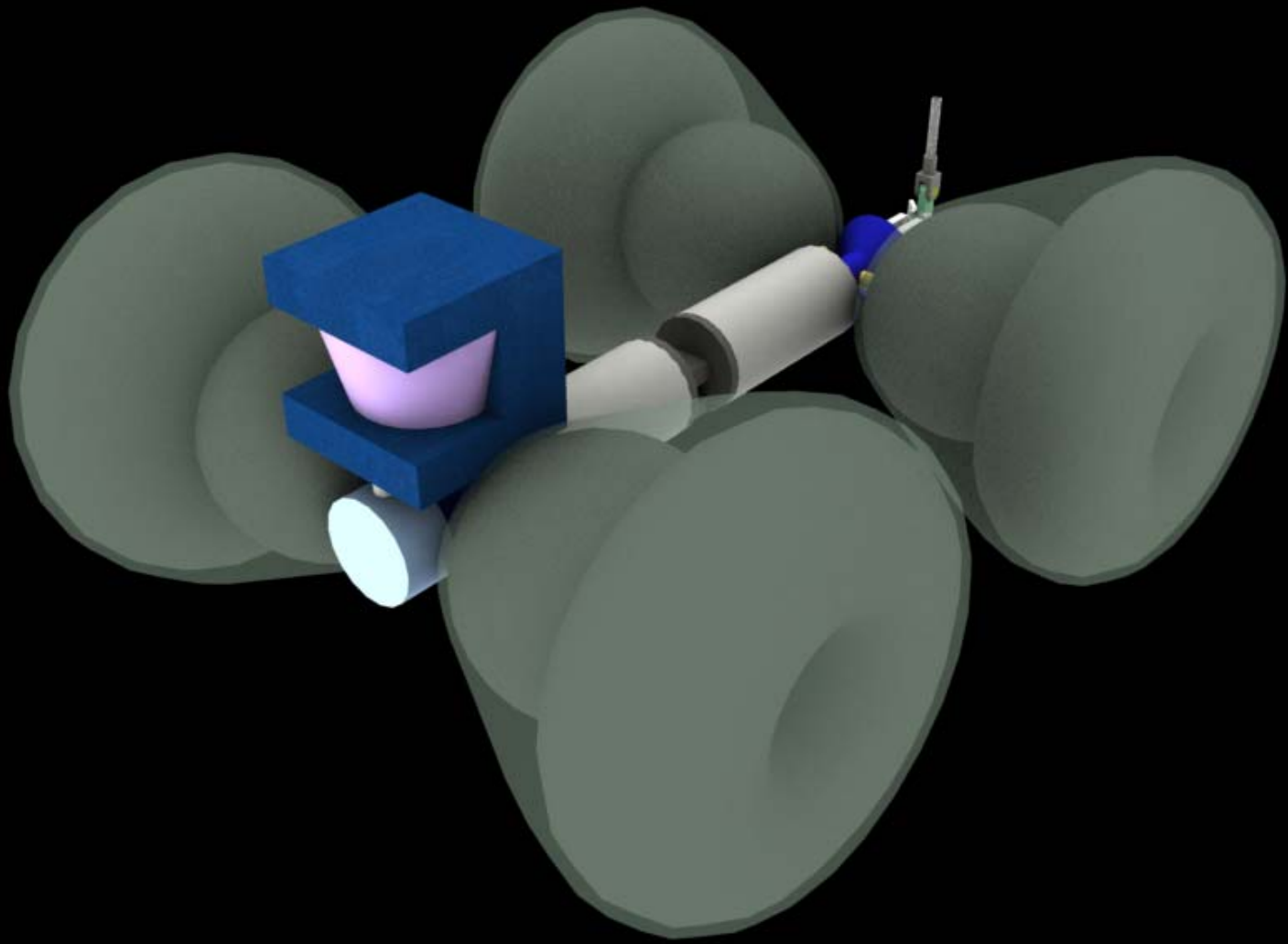
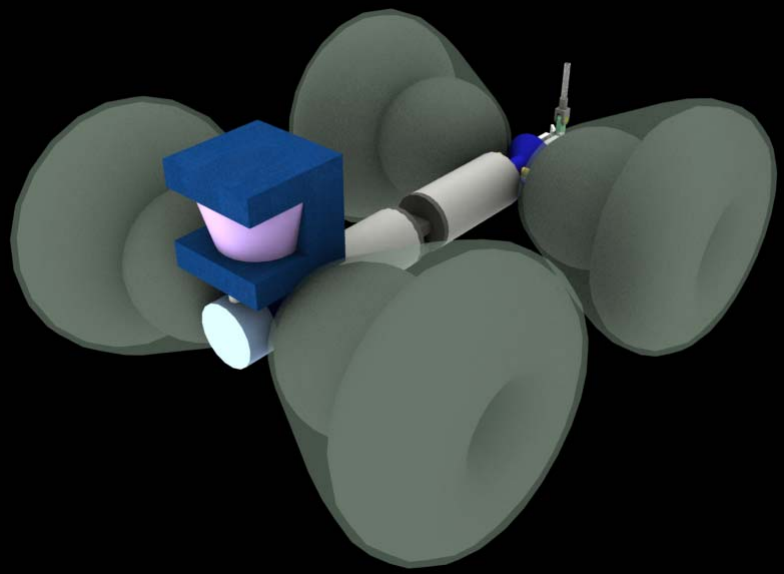
Magellan Borehole-Deployable Subterranean Rover

Preliminary Design

Concept Image



Specifications — Mechanical

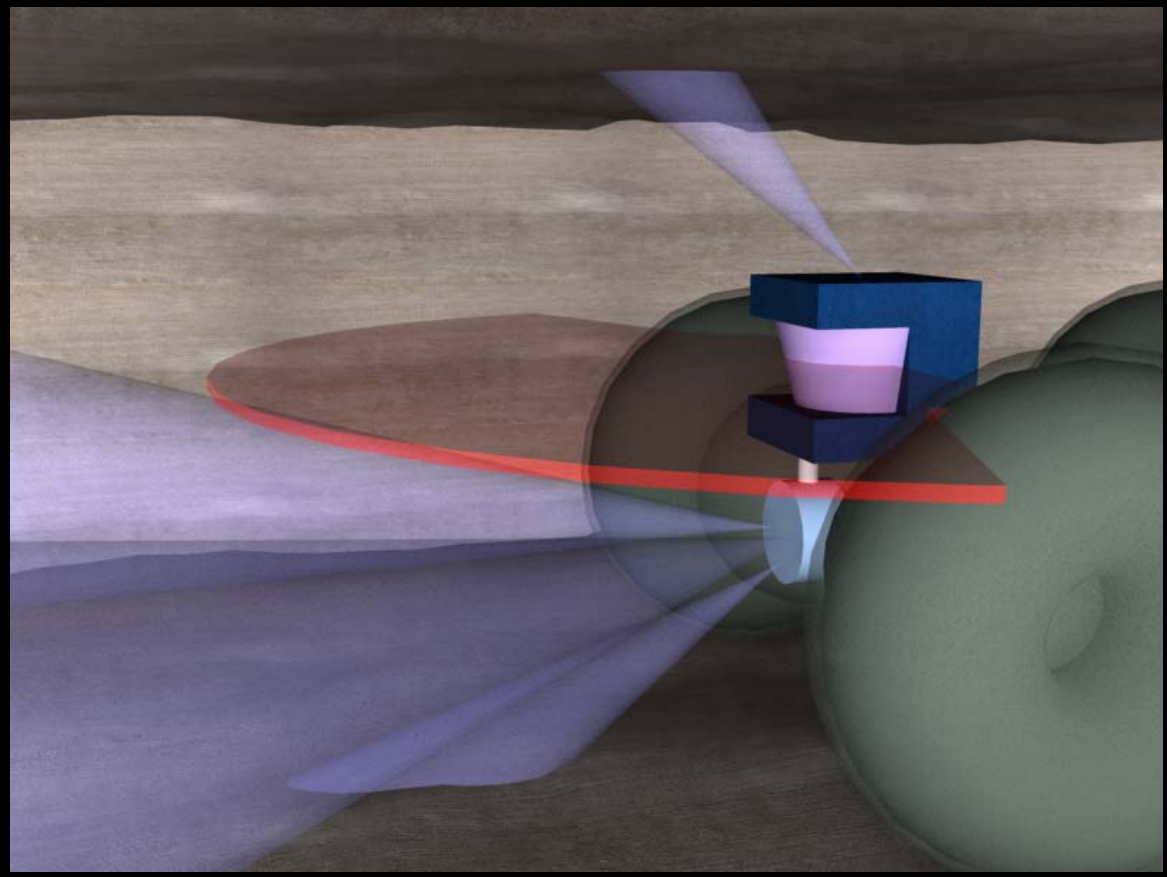


- 2 segment 4 wheeled rover
- Solid drive axles
- Steering via actuated center link
- Inflatable wheels
- Single purged and pressurized volume
- Deployable sensor payload
- Docking mechanism
- Compact deployment configuration

Electrical

- Locomotion and Actuation Motors (24VDC)
  - Front Drive
  - Rear Drive
  - Pneumatic Pump
- Sensing
  - Sonar and Laser Scanner
- Computing
  - PC/104+ form factor
  - Opportunistic Wireless Ethernet
  - Data logging

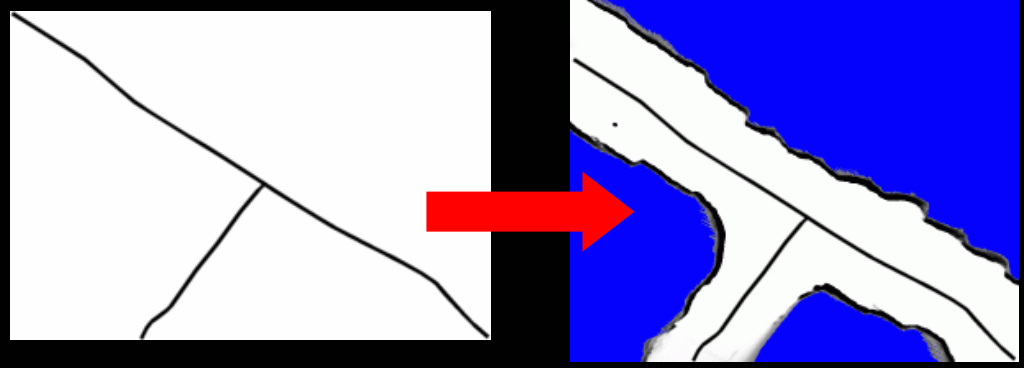
External Sensor Layout

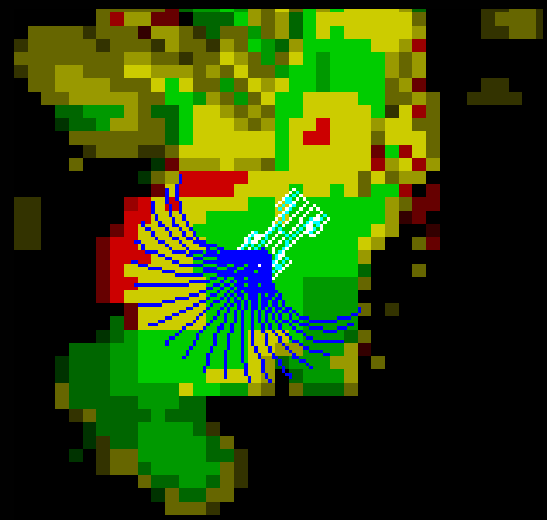


High Level Software

- Mapping and Navigation
  - Preprocess prior maps to plan mine traverse.
  - Perimeter traverses
  - Sector traverses

- Navigation
  - Node to Node Transition
  - Feature Identification: Corridor and Crosscut
- Wall Centering and Obstacle Avoidance

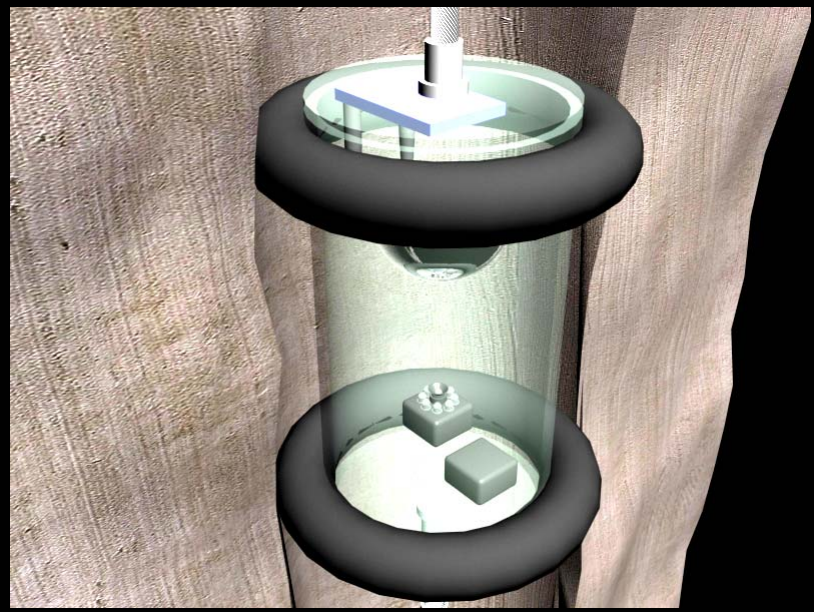




Major Subsystems

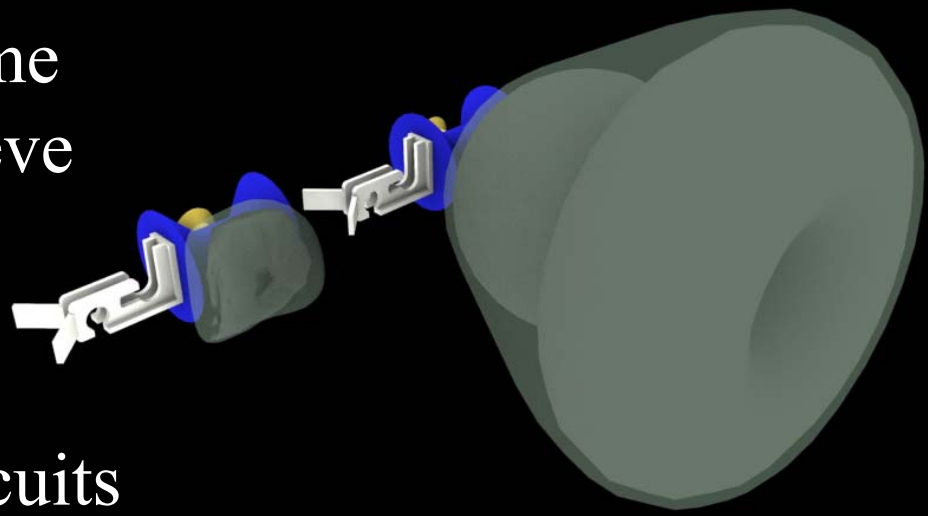
Base Station

- Borehole anchoring mechanism
- Tether to surface
- Video
- Compass
- Wireless Ethernet
- Detachable Snorkel
- Purged and pressurized



Inflatable Wheels

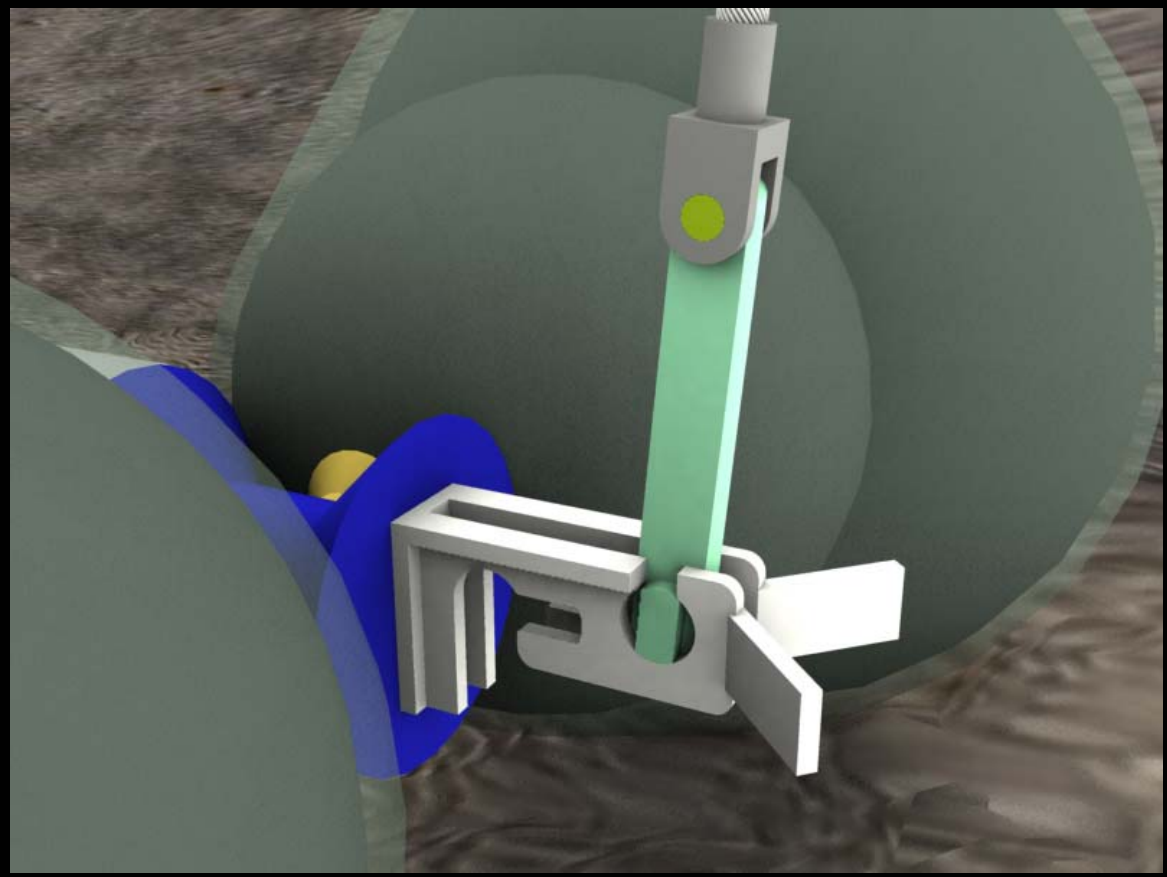
- Sphere and torus shaped internal pressure volume
- Enclosed in wheel sleeve
  - Stability/traction
  - Abrasion resistance
- Central pump drives independent wheel circuits
- Wheels inflated in mine
  - Air supplied by base station via detachable snorkel
- Wheels are vacuum deflated for recovery
  - Extra air is vented to mine



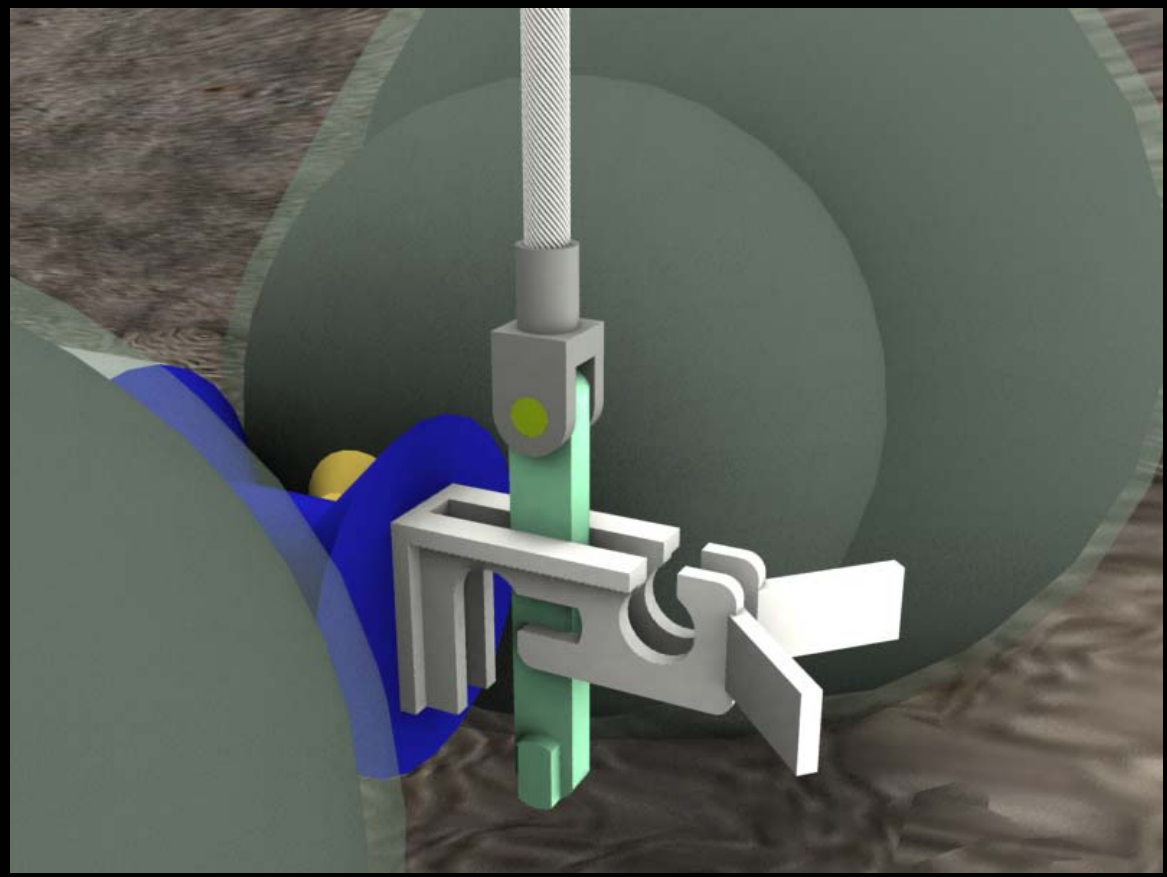
Docking Mechanism

- Passive hook and catch mechanism
  - disengages when robot is level
  - engaged by driving catch into hook

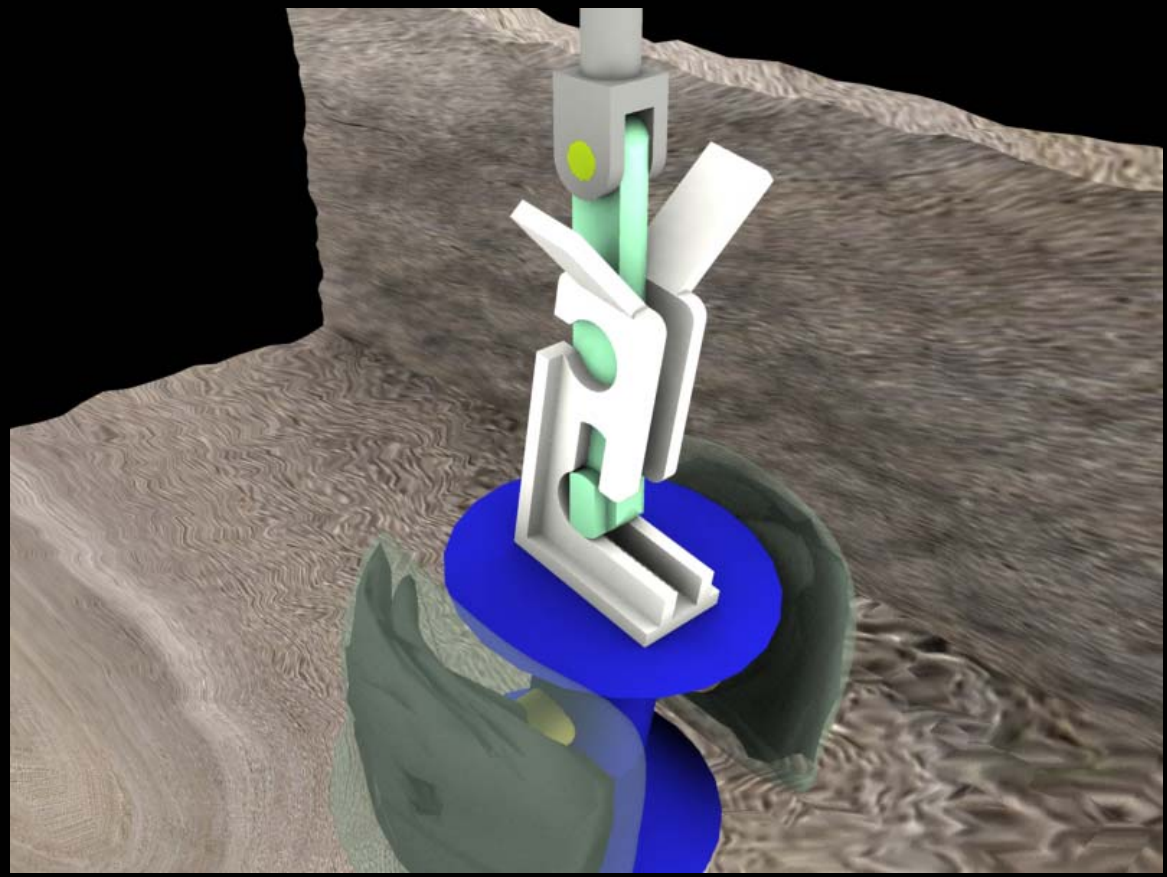
Docking Mechanism



Docking Mechanism



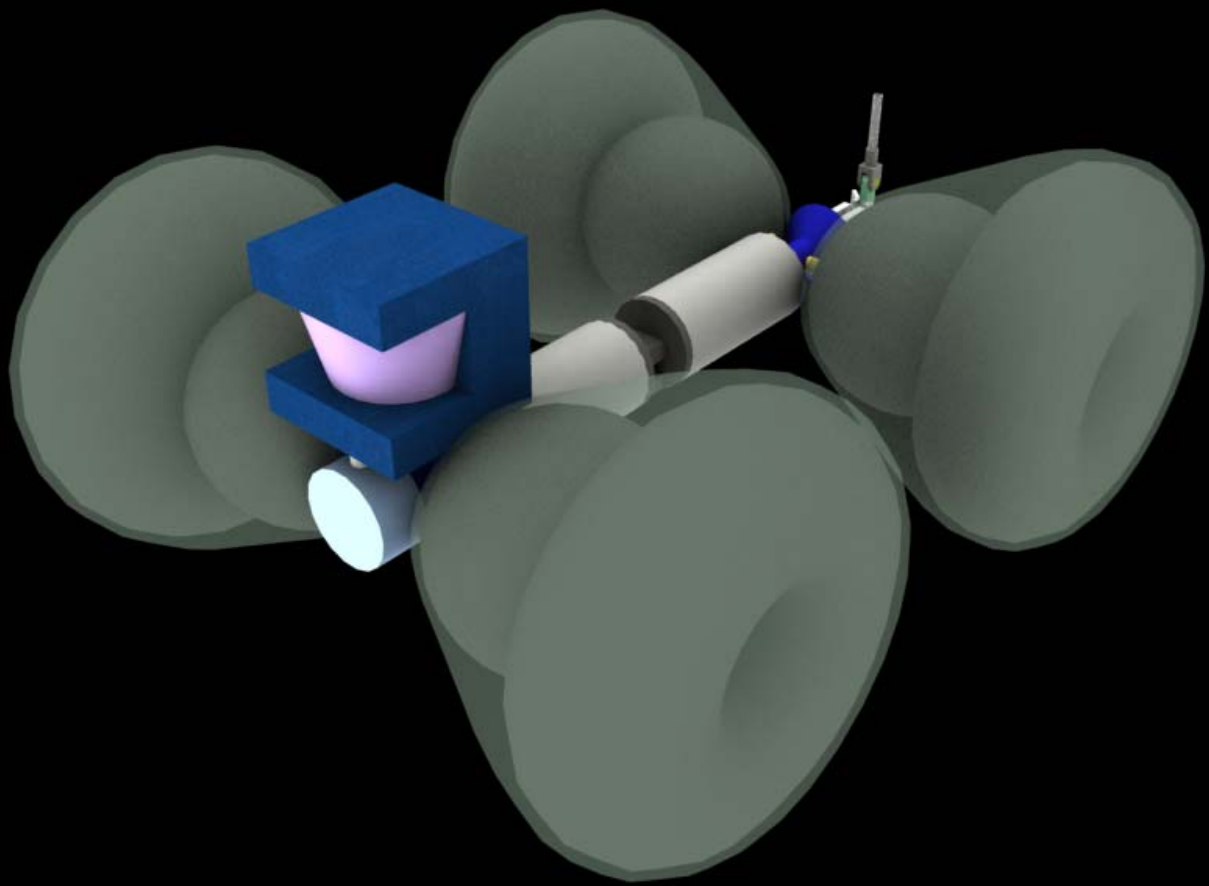
Docking Mechanism



Performance Goals

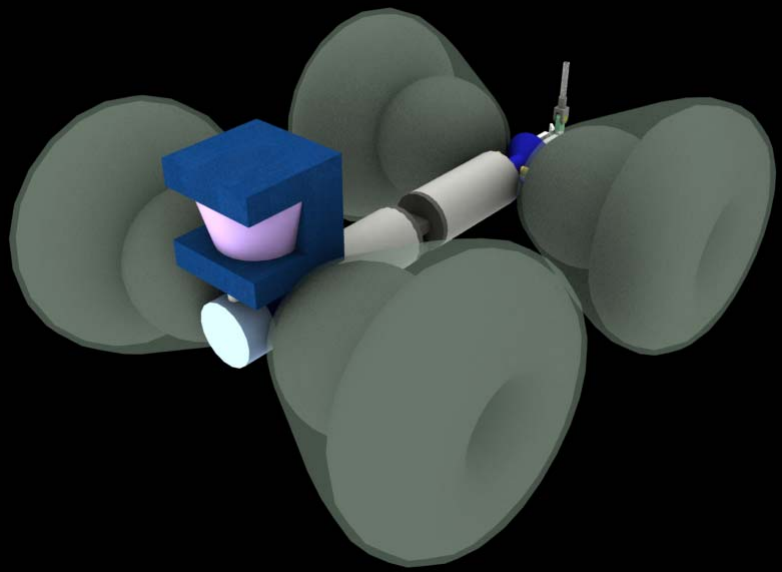
- < 70 lbs final mass
- > 1 mph top speed
- < 200 W average power consumption
  - 2.5 mile maximum straight line travel
  - 2 mile maximum safe straight line travel
  - .5 mile radius maximum circular traverse
- > 50 deployments MTBF
- < $20K
- < 2 Person field team

Questions



Visions for the Future

- 16-865/18-775: Advanced Mobile Robot Development
- BuoyBot for partially submerged mines.
- Magellan to be Developed Spring 2003



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Future of Subterranean Robotics

- Technologies to be Developed
  - Amphibious and Swimming Robots
  - Miniaturization and Borehole Deployment
  - Specialized Sensors for Subsurface
  - Autonomy
- Applications
  - Mine Mapping Services
  - Commercial Contacts
  - Monitoring Nuclear Storage Caverns
  - DoD operations in Caves Bunkers Aqueducts and Sewers
- Seeds for Enterprise
  - Disclosures Matured to Patents
  - Seeking Paid Applications
- Resources to Enable the Future
  - Line Item Earmark for Spring 2003
  - Proposal Portfolio in Preparation
  - Seeking Alliances

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