Autonomous Navigation for Urban Robots

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http://robotics.jpl.nasa.gov/tasks/tmr

Agenda

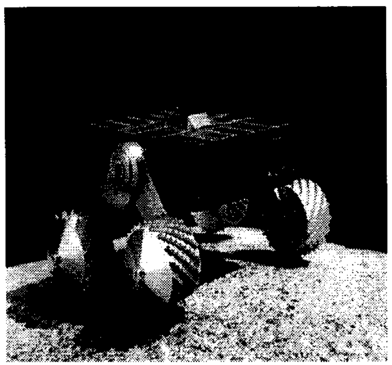
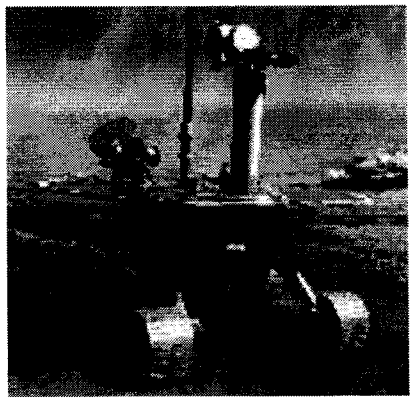
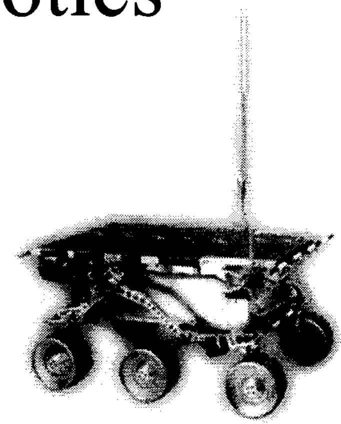
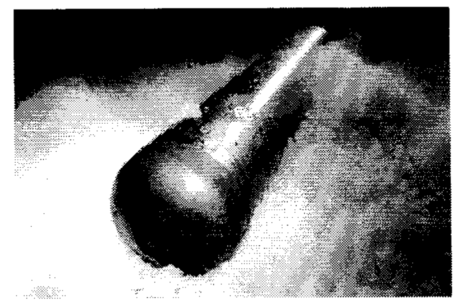
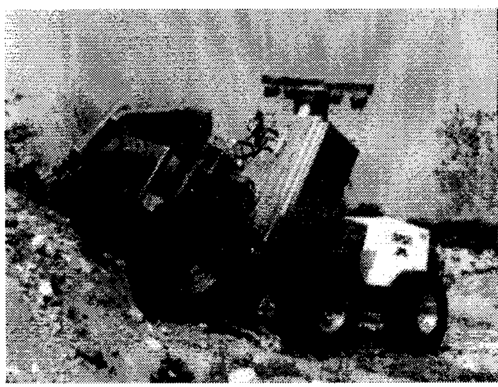
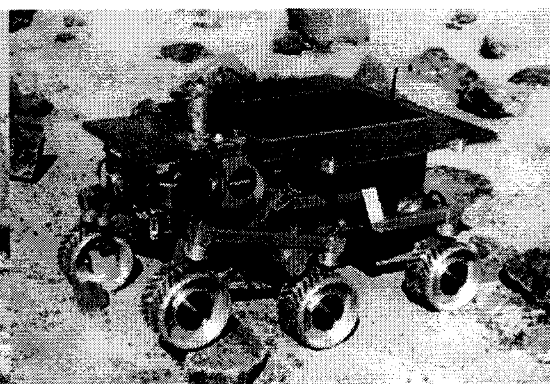
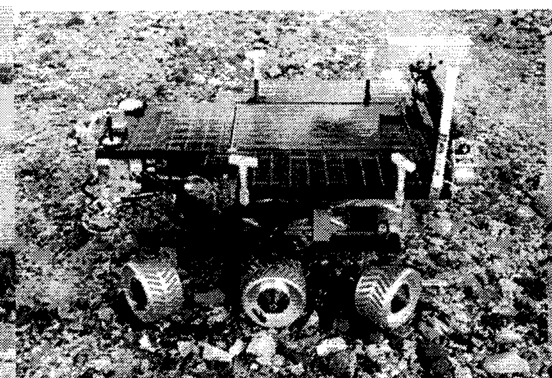
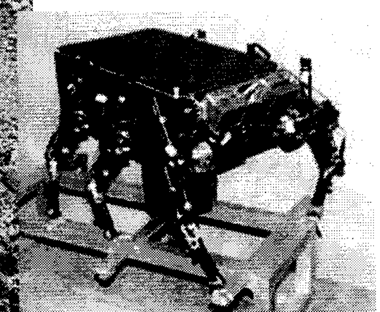
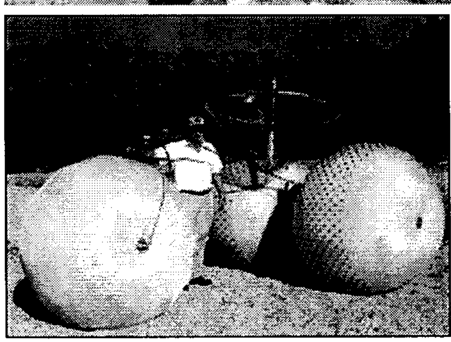
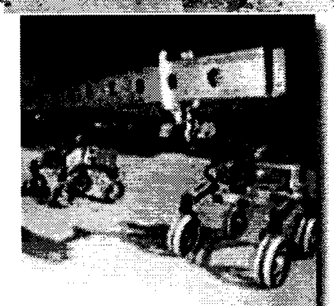
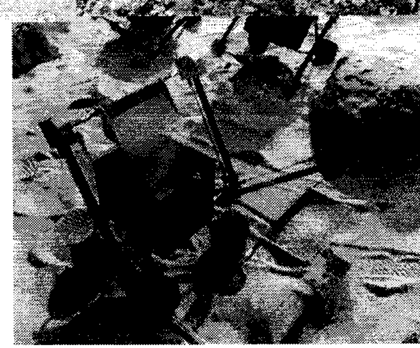
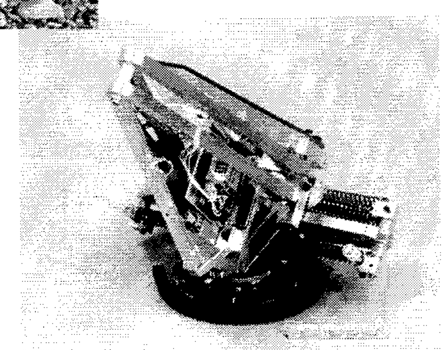
- General info
  - Autonomous def
  - Autonomous JPL Robotics
  - The Urban Robot
- Chassis
- Processors & Navigation sensors
- Perception sensors
  - Stereo cams
  - Omnicam
  - FLIR
- Behaviors
  - Obstacle avoidance & Safeguarded Teleop
  - Visual servoing
  - Kalman Filter& Path following
  - Mapping
  - Stair climbing
- Tie-in to MER
- Hybrid
- Video
- Demo

Autonomy Overview

Autonomy

- What does "autonomous" mean?
  - Not controlled by others or by outside forces; independent
  - Independent in mind or judgment; self-directed

JPL Robotics

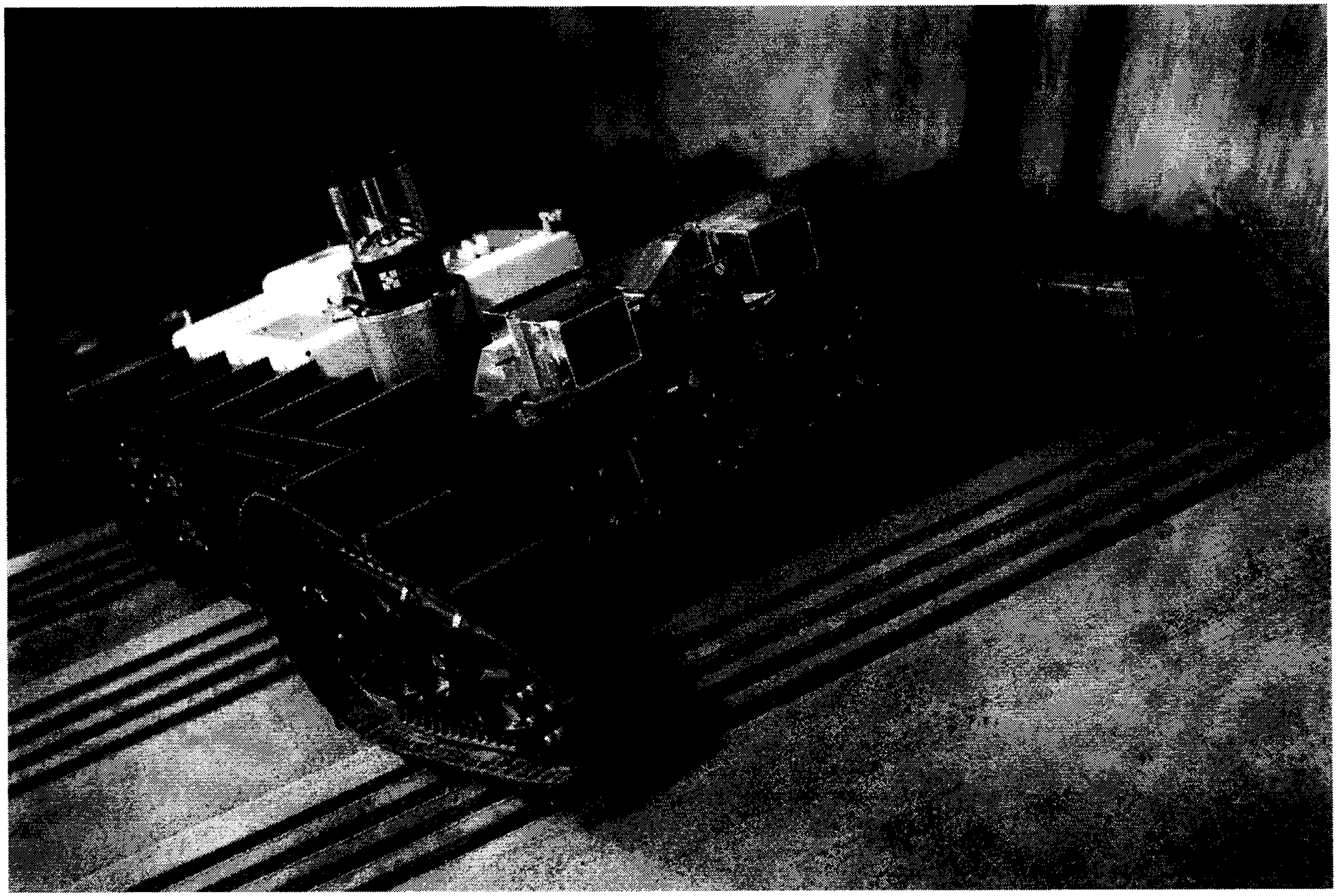
JPL Spacecraft

Autonomous Robots

On-board autonomy allows a system to:

- Adapt to a dynamic or poorly defined environment
  - Navigate through obstacle clutter
  - Provide better control than the operator using sensor feedback
- Compensate for poor, lost, or no communication
  - Seek a previously determined goal or carry out a predetermined mission without user control
  - Find better communication spots or backtrack to regain comm
- Reduce operator effort
  - Operate without using complex control commands
  - Multiple robots can be managed simultaneously

Earthbound Mission: JPL Urban Robot



(Urbie)

Objectives

The primary goal of Urbie is to provide remote awareness.

Send a robot into dangerous environments instead of people.

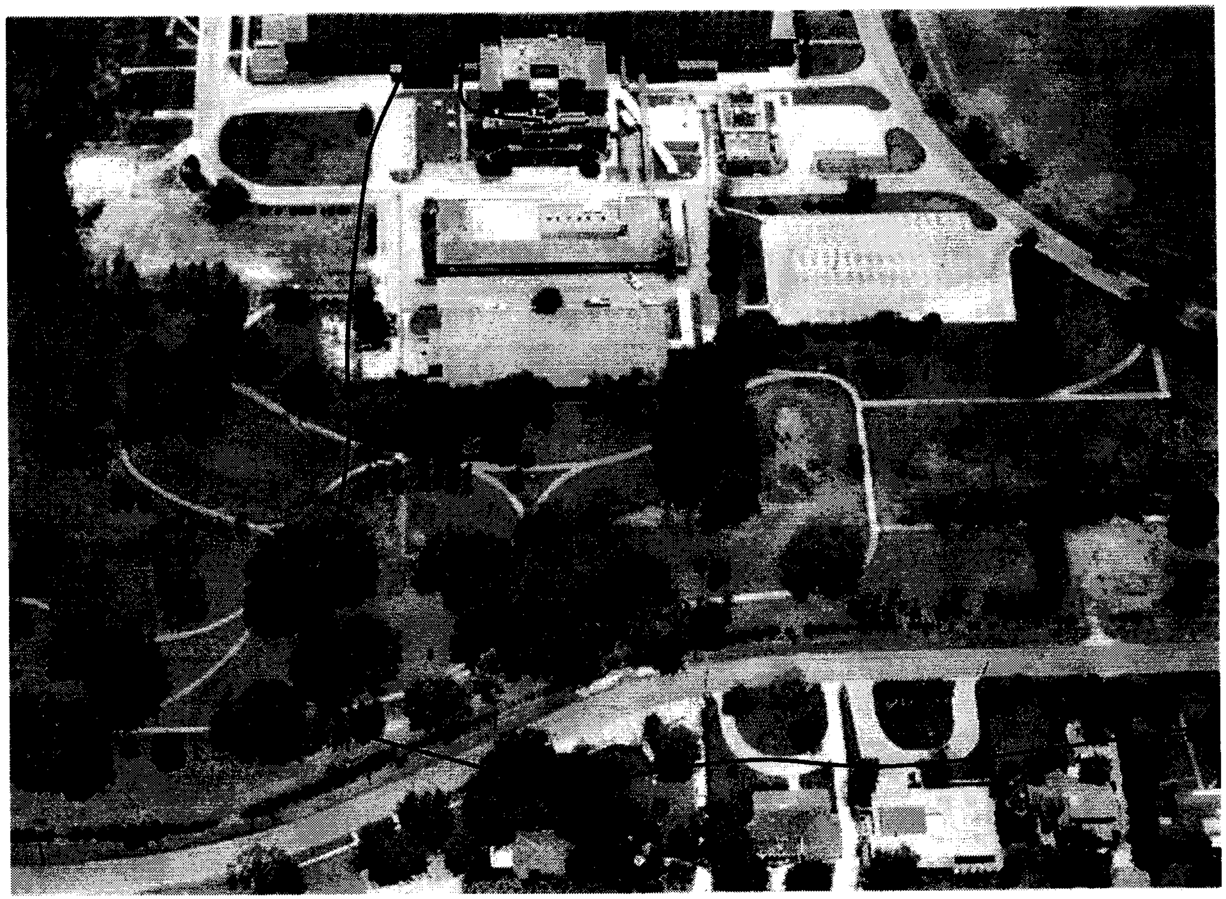
Applications:

- Stricken buildings
  - Gas leak
  - Radiation
  - Fire
  - Earthquake
- Urban search and rescue
- Urban reconnaissance

Objectives

- Remote Sensing
  - Carry various, complimentary sensors (active and passive)
  - Relay knowledge of terrain for others that follow
- Travel using autonomous behaviors
  - Use of self direction
  - Accomplish goals quickly
- "Backpackable"
  - Size
  - Weight

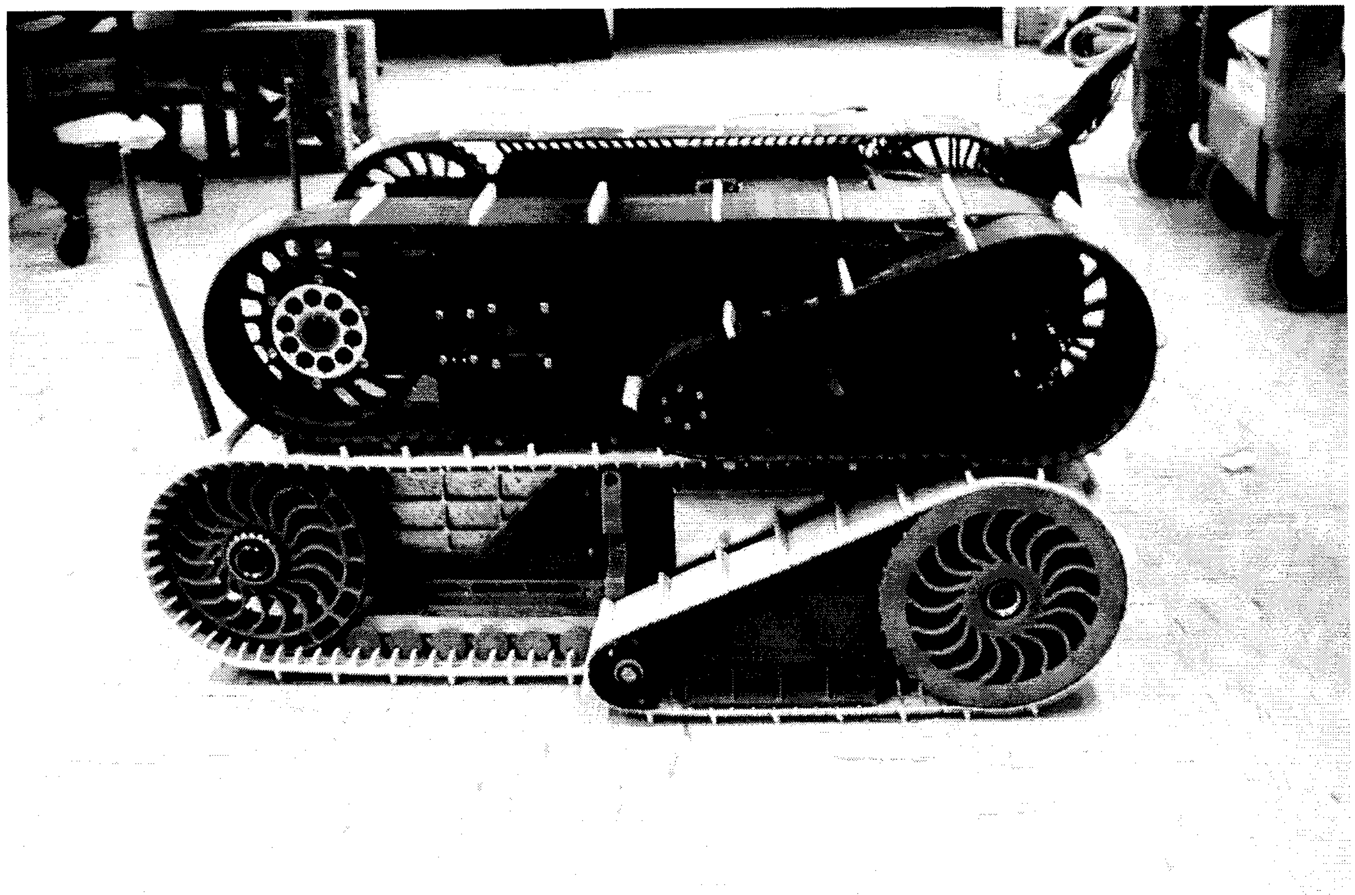
Example Scenario



Hardware and Electronics

Chassis

- Novel design
- Rugged
- Tracked for stairs
- Fast (~2m/sec)

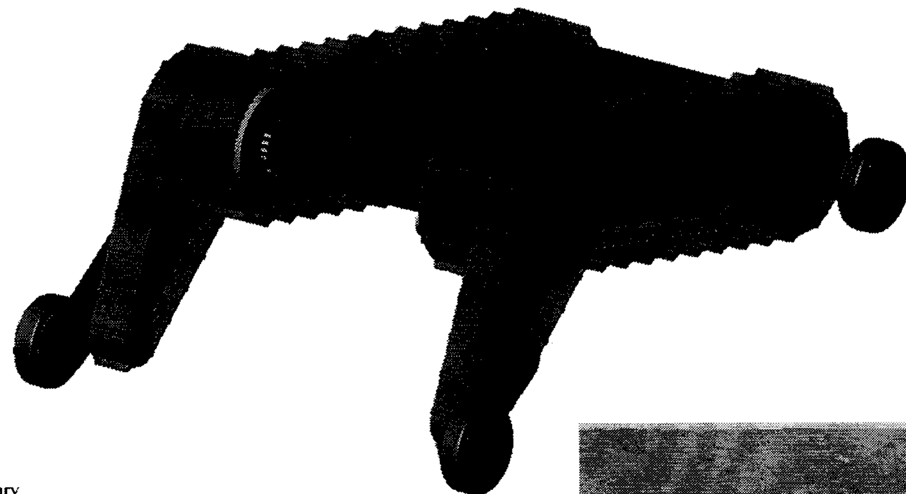


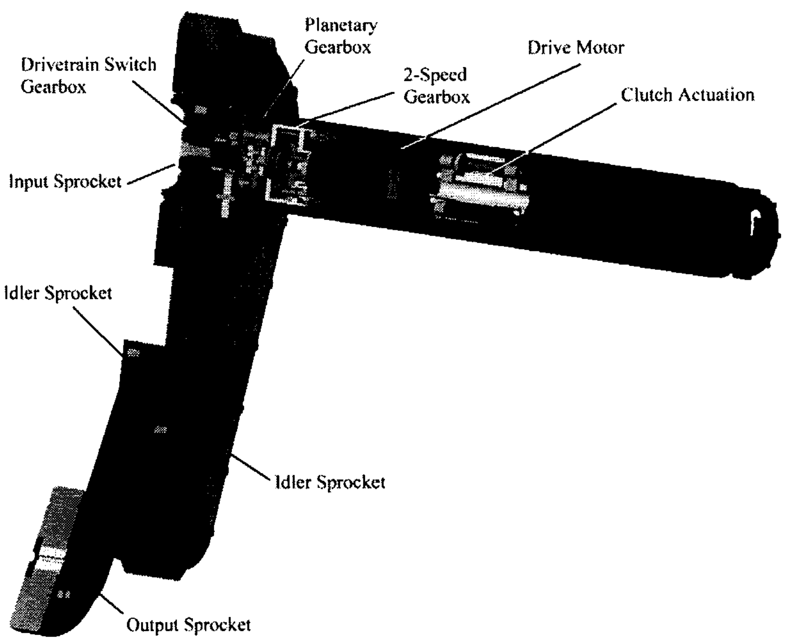
Driving Chassis

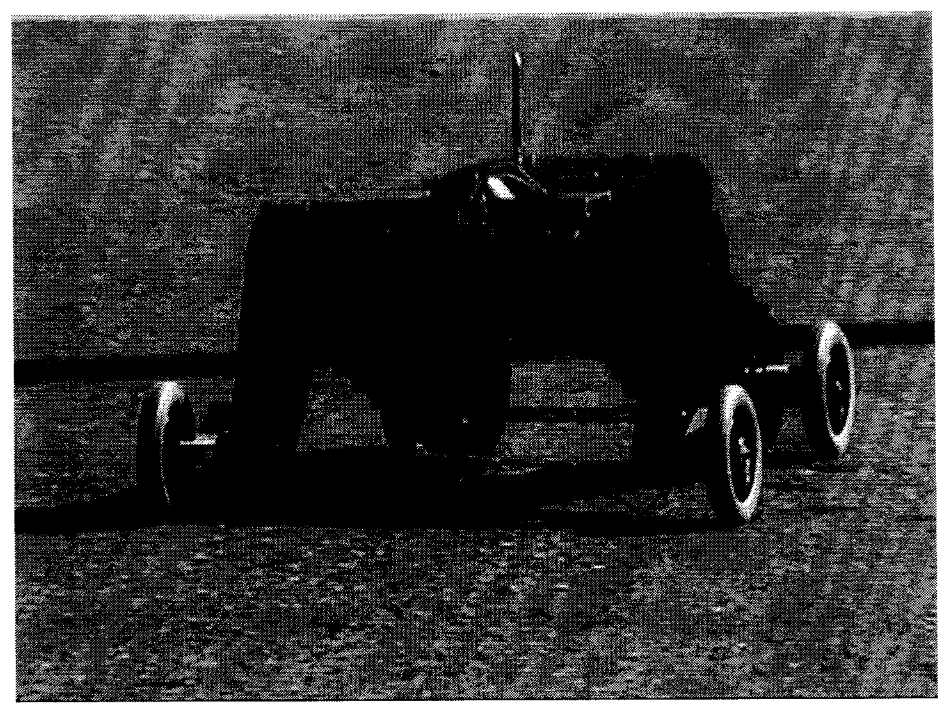
Obstacles

Stairs climbing

Hybrid Locomotion







Hybrid Prototype

QuickTime™ and a
Video decompressor
are needed to see this picture.

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Video decompressor
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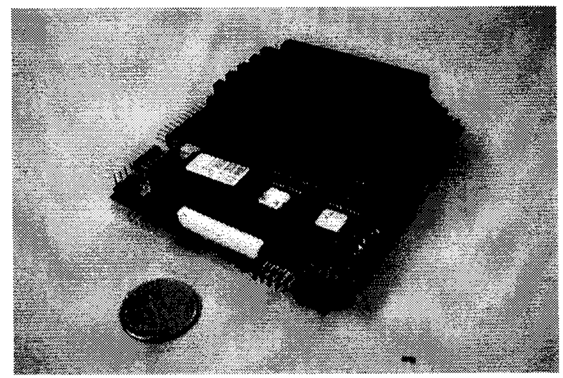
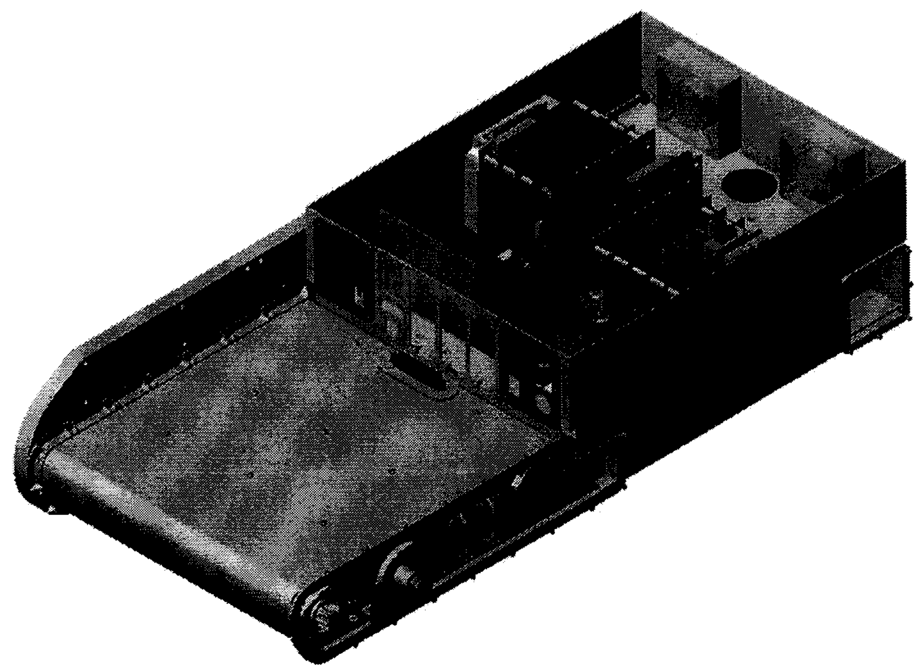
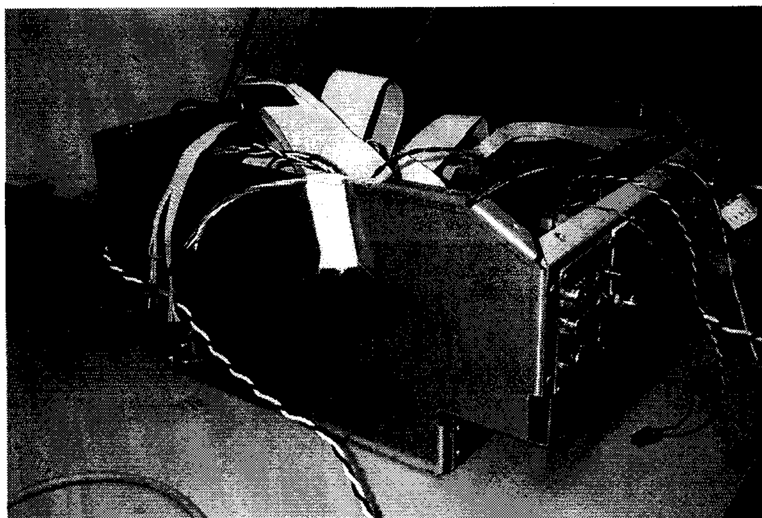
Processors & Navigation Sensors

- Navigation processor & Vision processors (PIII)
- Inclinometer & magnetometer (compass)
- 3-axis gyros
- 3-axis accelerometers
- GPS

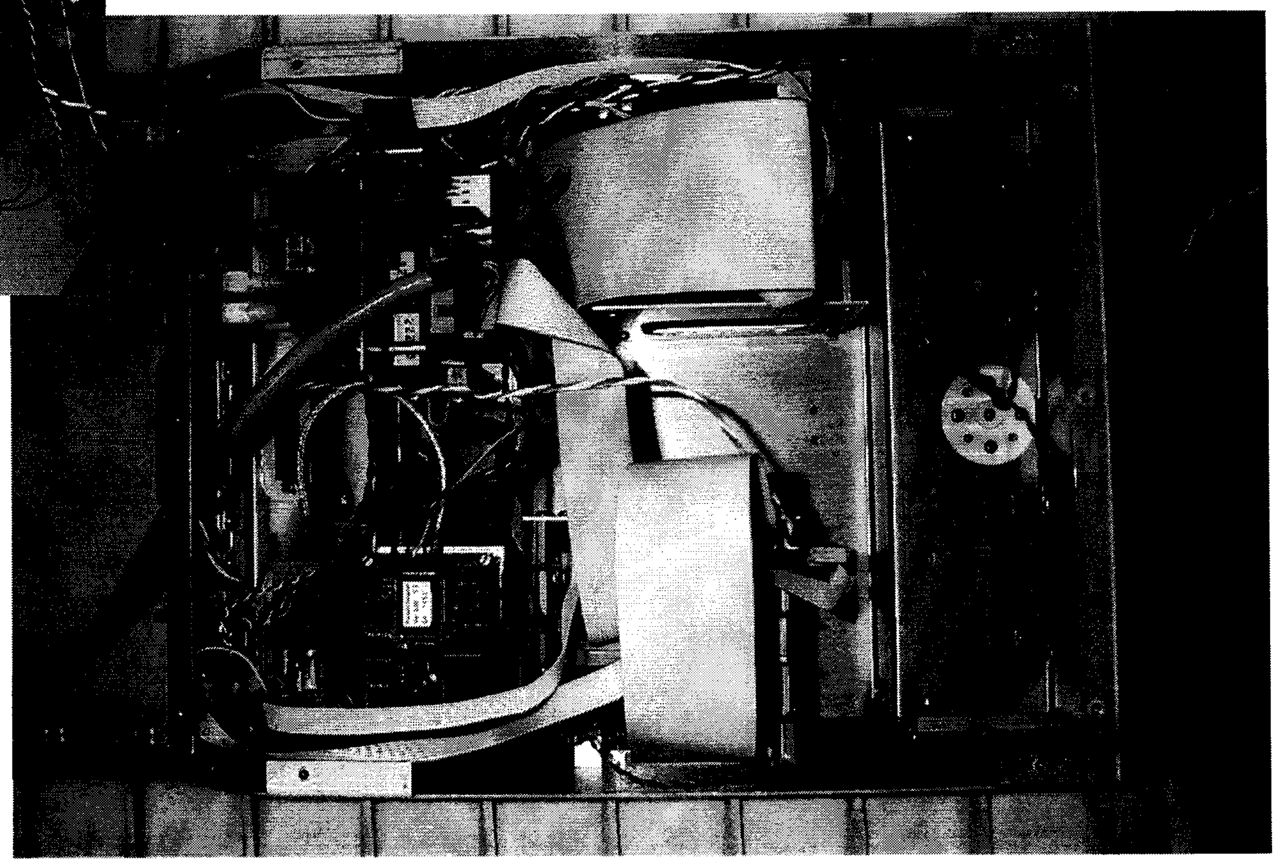




Electronics Box



- Small package
- Contains all navigation sensors
- Capable of intensive vision processing



Perception Sensors: Stereo Cameras

- Provide a 3-D view
- Passive sensors
- Lets the user "see" through robot eyes
- Used by autonomous behaviors

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GIF decompressor
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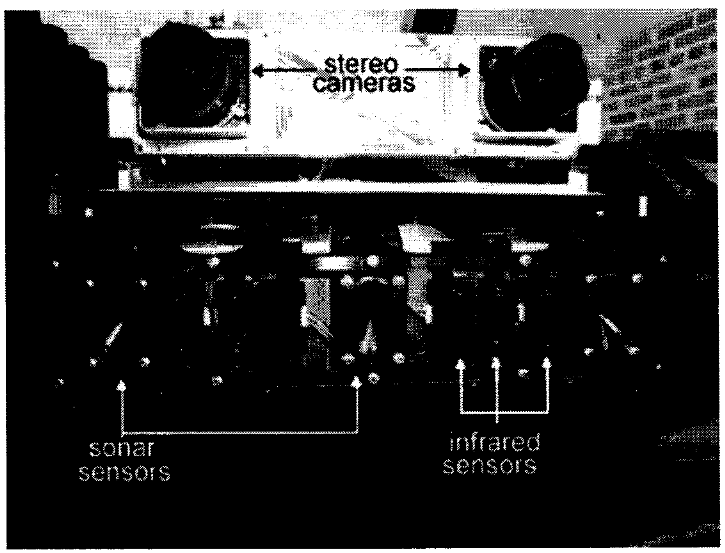

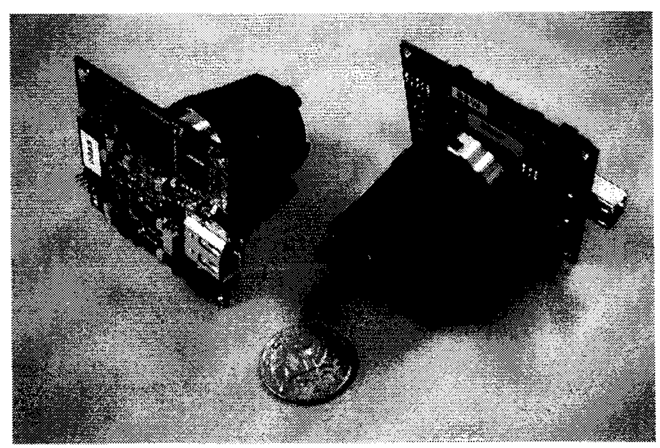

Perception Sensors: Omnicam

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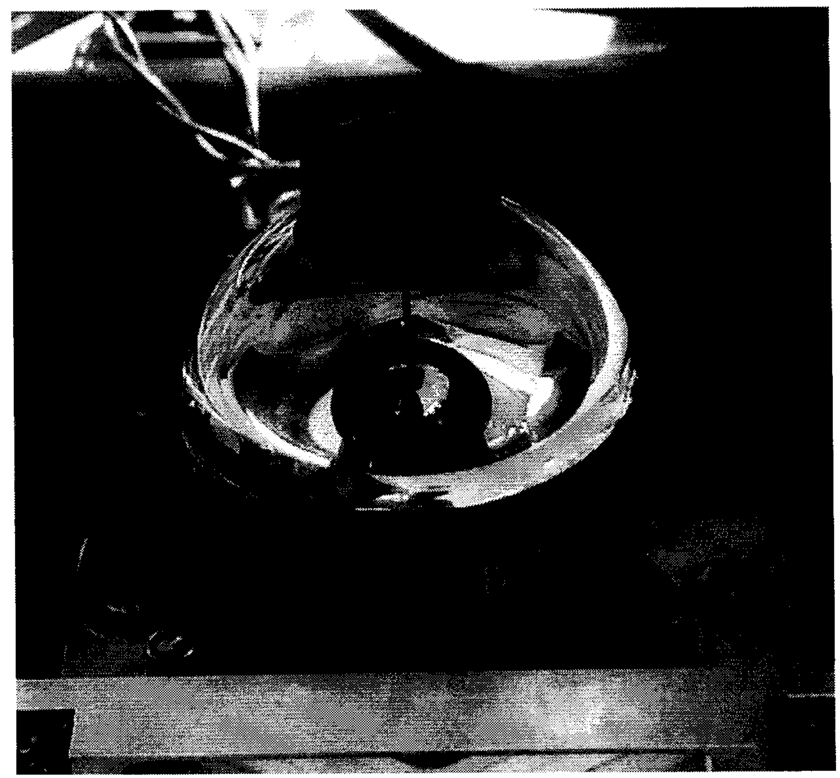
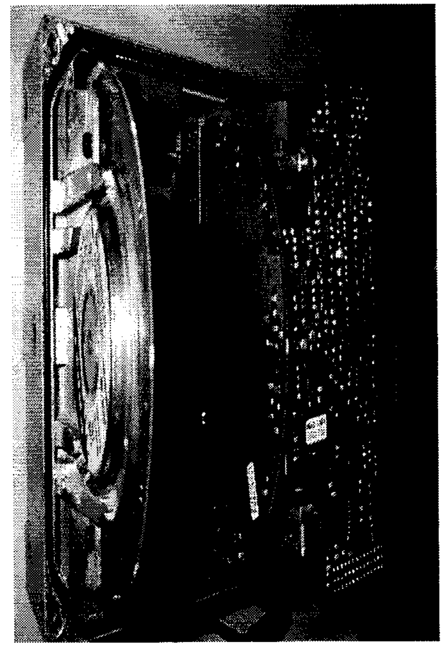
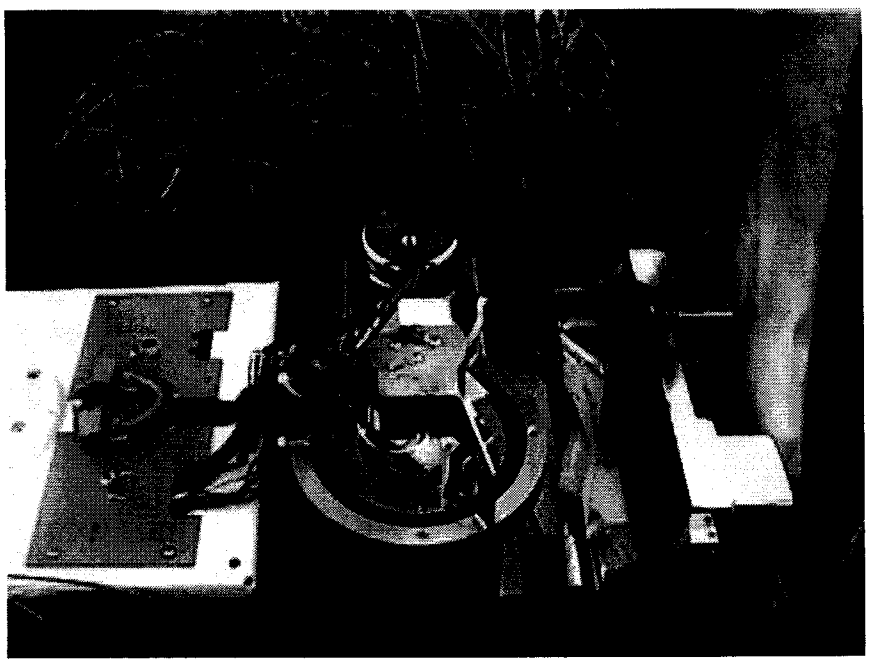


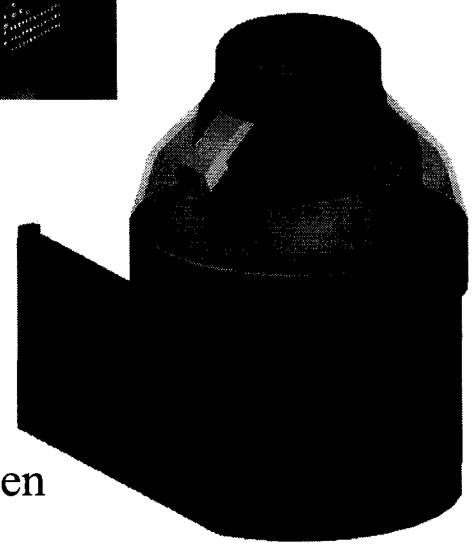
- Hemispherical Imager
- Passive sensor
- Provides a panoramic view
- Used for driving behaviors

Perception Sensors: Ladar

- Infrared laser rangefinder
- Returns distance to obstacles
- 180 degrees field of view
- Works in complete darkness



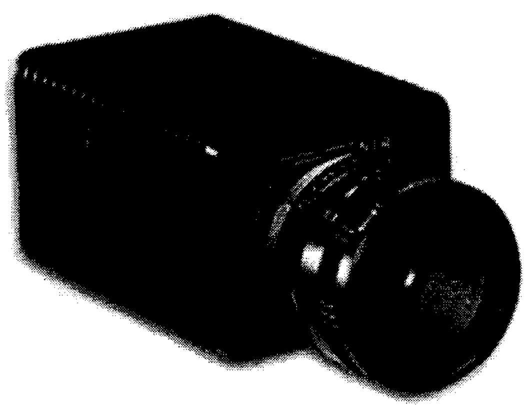




- 2-axis
- Next gen

Perception Sensors: Infrared Camera

- Infrared (thermal) imager
- Passive sensor
- Works in darkness



Autonomous Behaviors

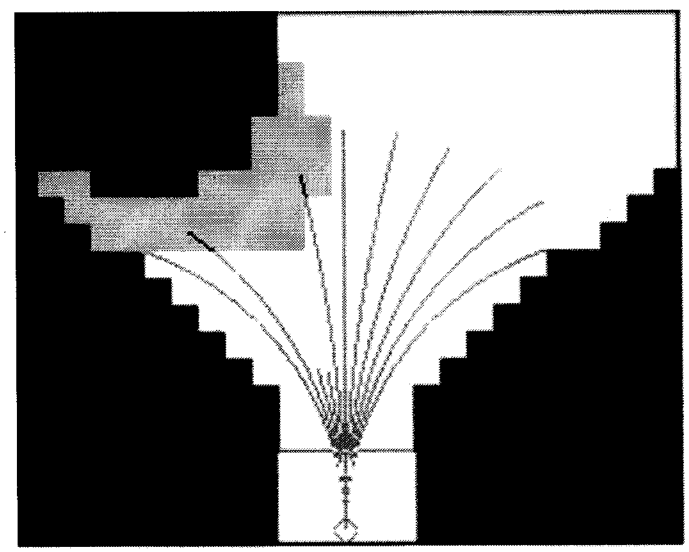
Visual Obstacle Detection

- Uses a pair of images and camera models.
- Performs comparison of pixels to generate thousands of disparity measurements.
- Uses camera models to convert raw disparity pixels into 3-D points.

QuickTime™ and a
H.263 decompressor
are needed to see this picture.

Visual Obstacle Avoidance

- Generates an obstacle map from the stereo range map.
- Plots driving arcs through the obstacle map.
- Chooses the arc that is clear(est) of obstacles.
- Cycle time is 5-10 Hz



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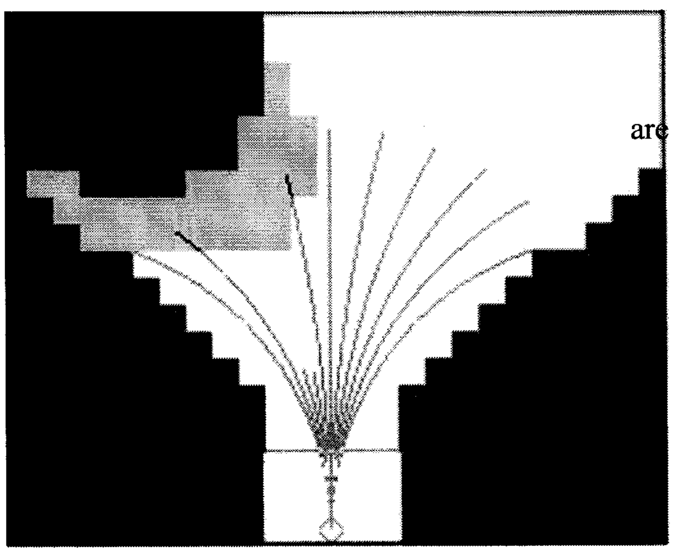


QuickTime™ and a
DV - NTSC decompressor
are needed to see this picture.

Visual Obstacle Avoidance

- Can be combined with other driving behaviors
- Provides a safeguarded user driving mode

QuickTime™ and a
Video decompressor
are needed to see this picture.

External view

QuickTime™ and a
Video decompressor
are needed to see this picture.

Robot-eye view

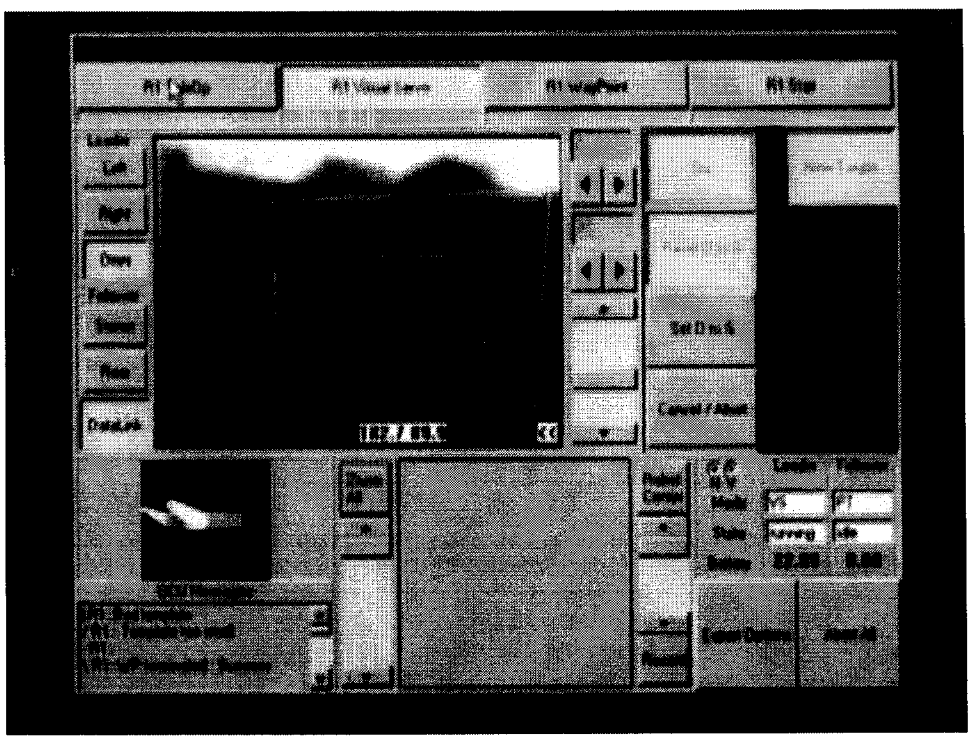
Ladar Obstacle Avoidance

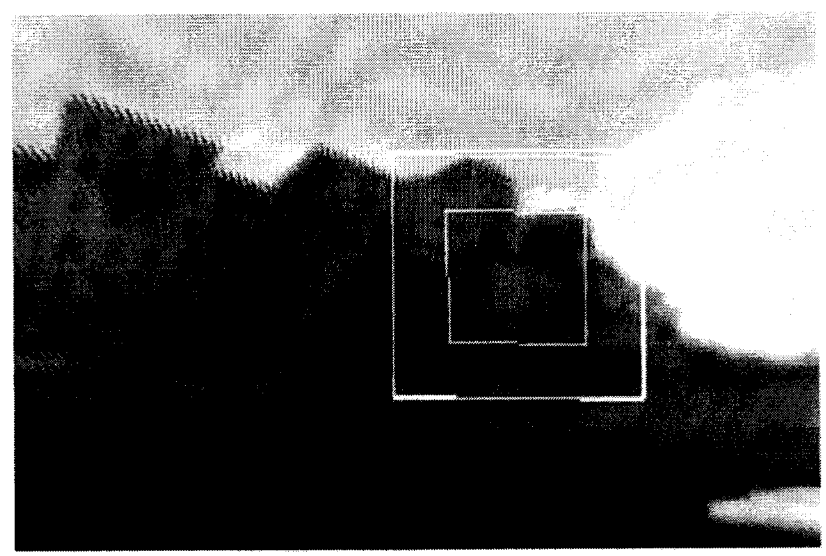
- Uses the same navigation software
- Visible light not necessary
- Compliments vision algorithm

QuickTime™ and a
H.263 decompressor
are needed to see this picture.

Template Tracking

- "Visual Servoing" from CMU
- Tracks part of a camera image and directs the robot towards it
- Does a large search when the template is lost
- Driving mode used to direct Urbie to a goal with one command

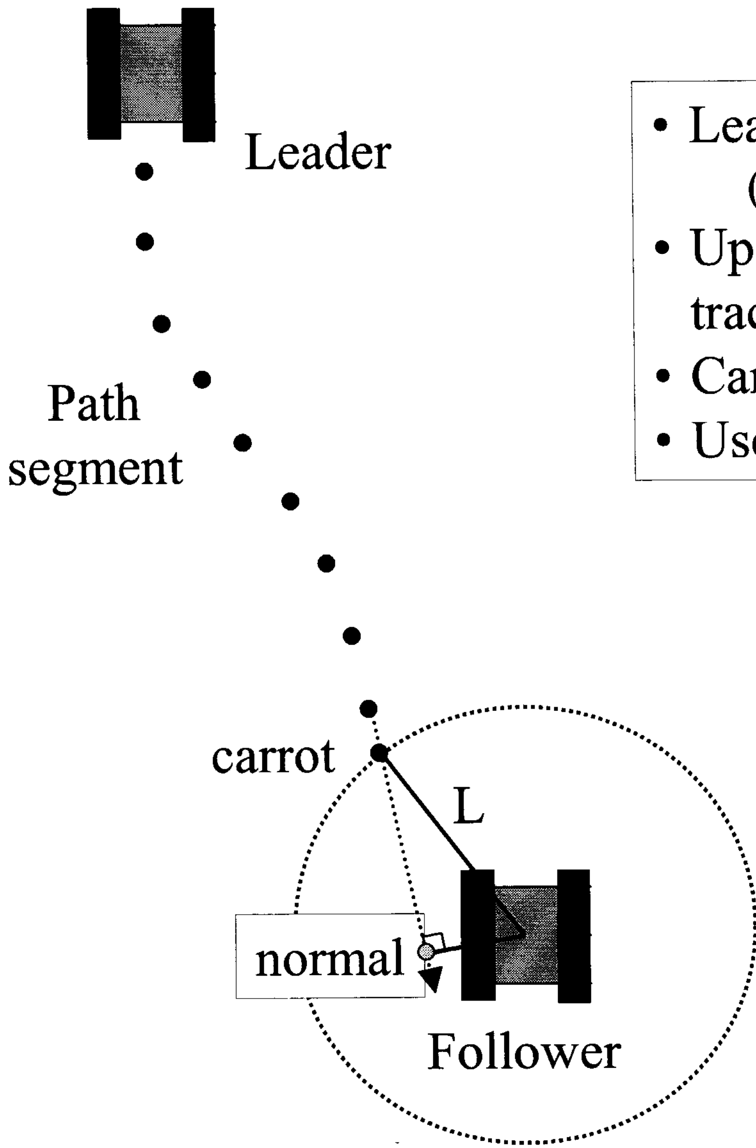




Position Estimation

- “Kalman filter” used to estimate Urbie’s position and orientation (roll, pitch, and heading)
- Runs at > 256 Hz
- Sensors used:
  - 3-axis accels
  - 3-axis gyros
  - GPS
  - Motor encoders
  - Compass / Inclinometers

Path Following Behavior



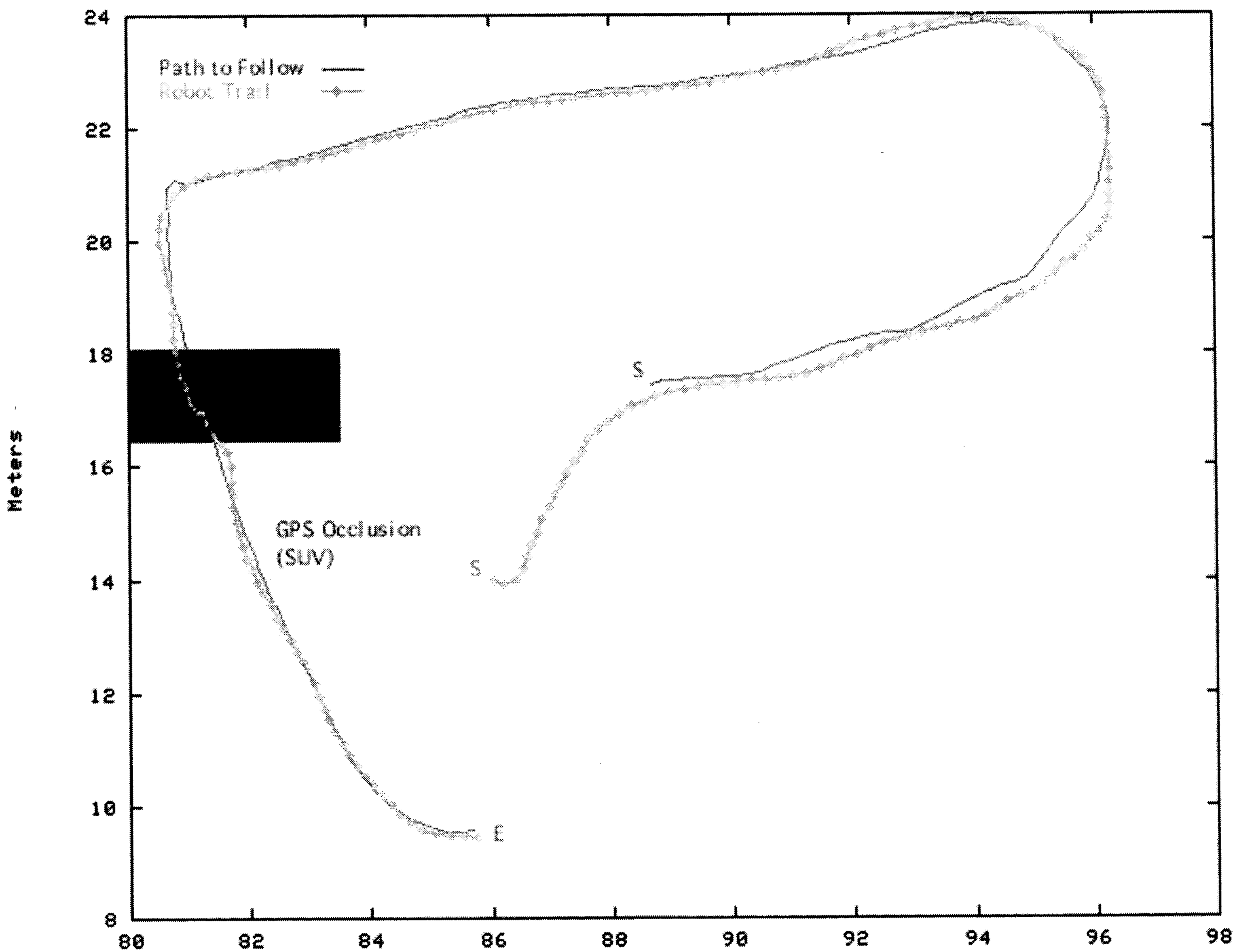
- Leader transmits path segment to follower
  (Set of subgoals separated by ~20cm)
- Update a *carrot* goal in real-time; estimate track speeds to run through the carrot
- Can be used for path backtracking
- Useful to recover from a comm dropout

Path Following Results

- Robot directed to follow it's own path
- Path goes through a GPS occlusion (under an SUV)

QuickTime™ and a
H.263 decompressor
are needed to see this picture.

Path Following Results



Path Following with Obstacle Avoidance

QuickTime™ and a
H.263 decompressor
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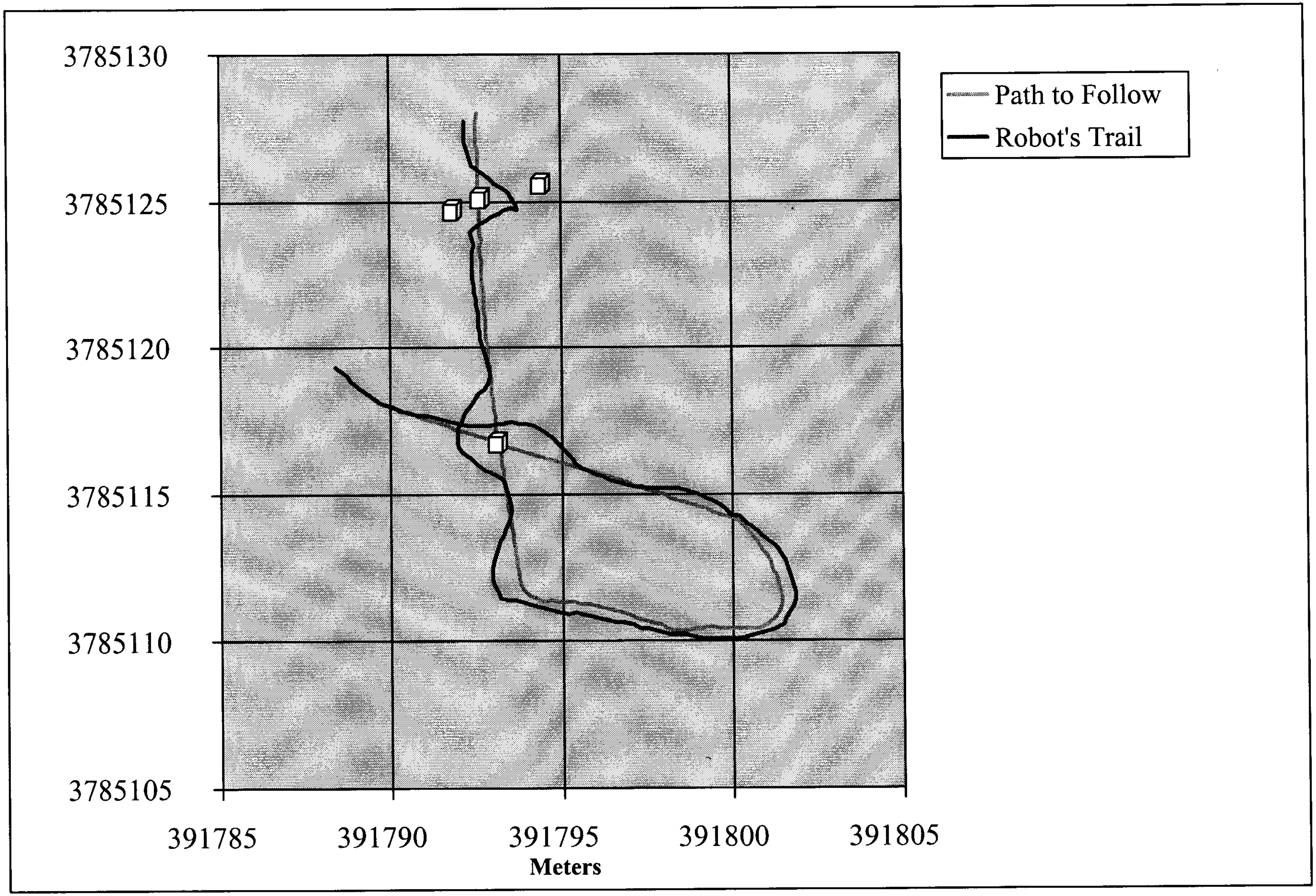
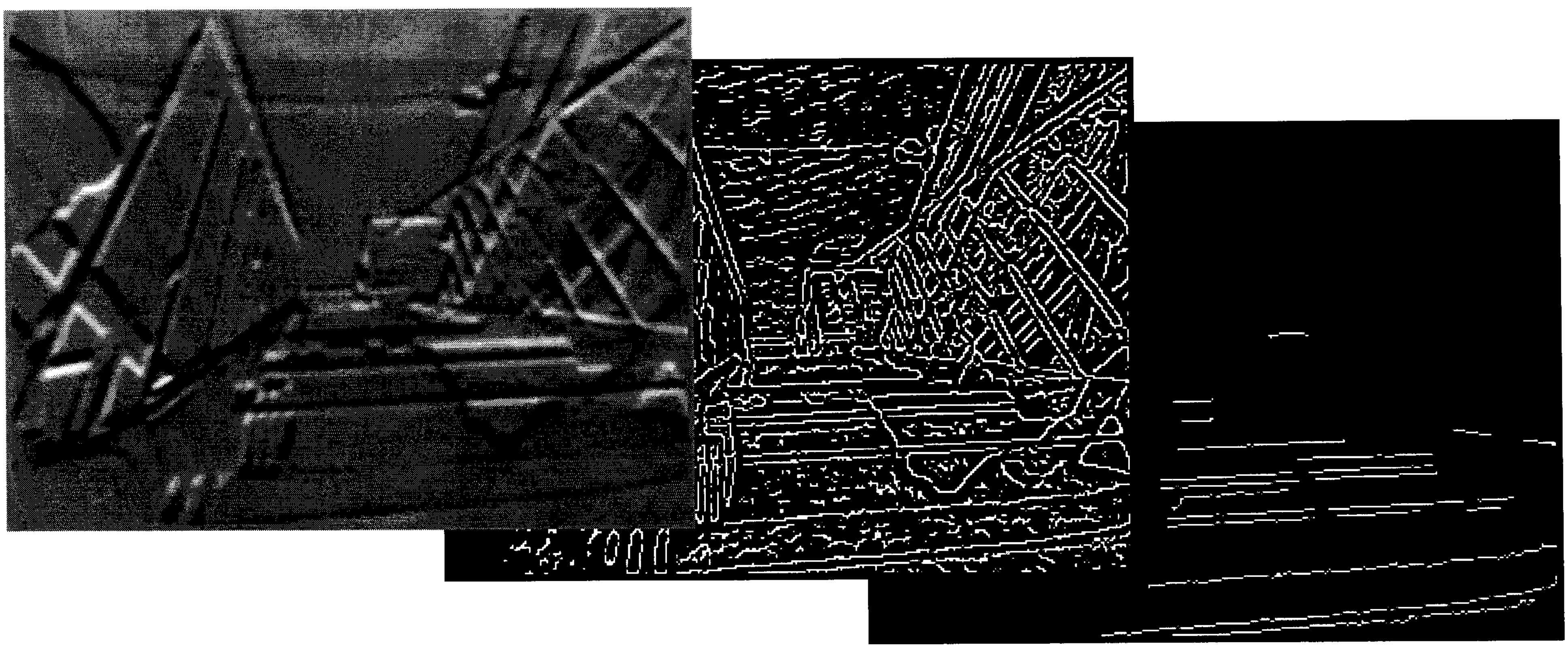
Path Following with Obstacle Avoidance



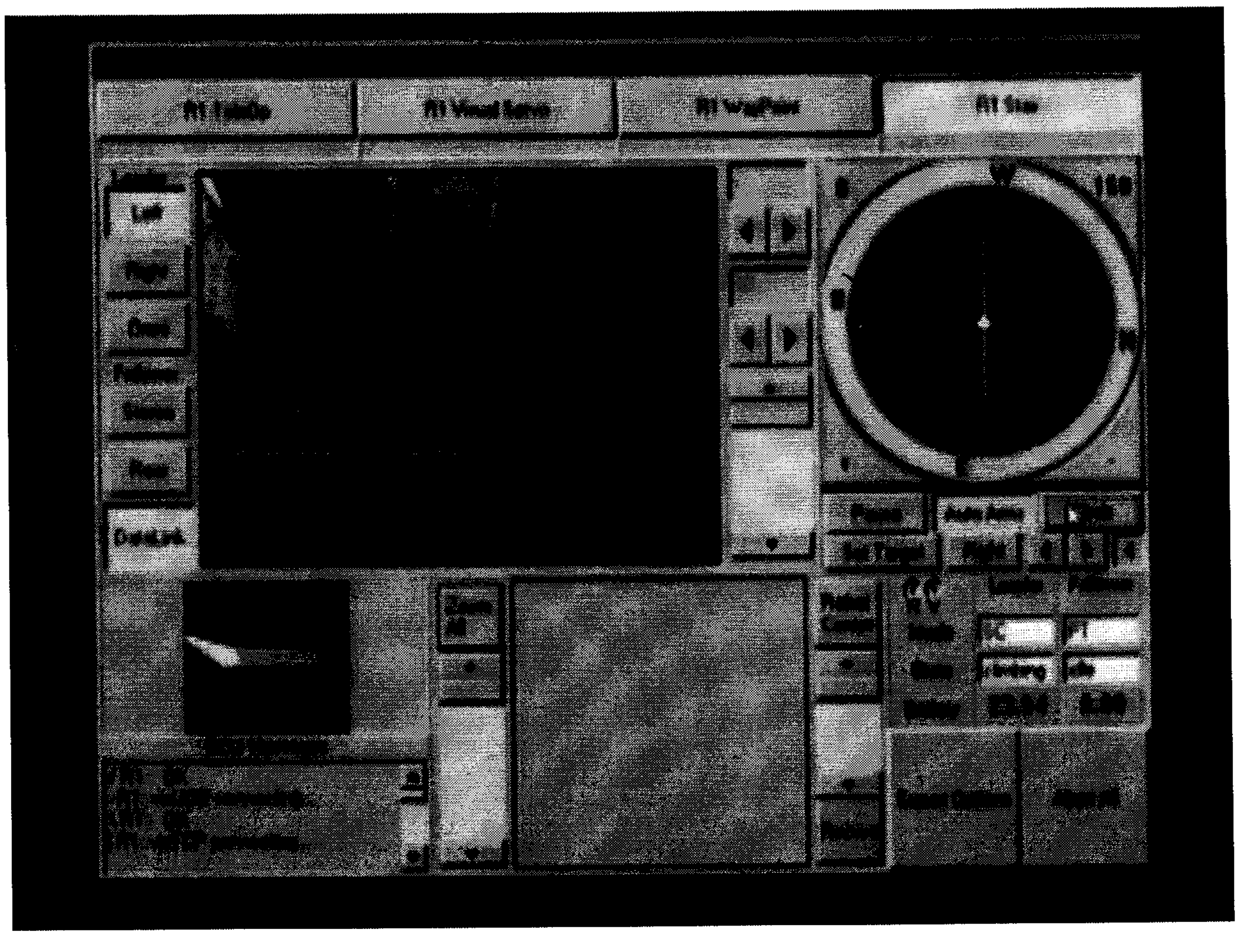
Visual Stair Climbing

- A visual algorithm extracts lines from one camera image
- The robots heading and the distance to the sides of the stairs are estimated
- Urbie steers perpendicular to the lines and veers away from the stairwell walls
- When there are no steps in sight a gyro is used to estimate heading



Visual Stair Climbing

- Urbie can climb multiple flights of stairs with one command (the record is 12!)
- The autonomous behavior performs better than user control



USC Operator Interface

Visual Stair Climbing

QuickTime™ and a
H.263 decompressor
are needed to see this picture.

Ladar Guided Stair Climbing

- Uses ladar range points to find stair walls and flight back wall
- Compliments vision algorithm

QuickTime™ and a
H.263 decompressor
are needed to see this picture.

- Algorithm run in simulation with real stair climbing data
- Right green points show a line fit to wall data
- Center green and red lines show heading estimated from wall line and from the gyro

Ladar Guided Stair Climbing

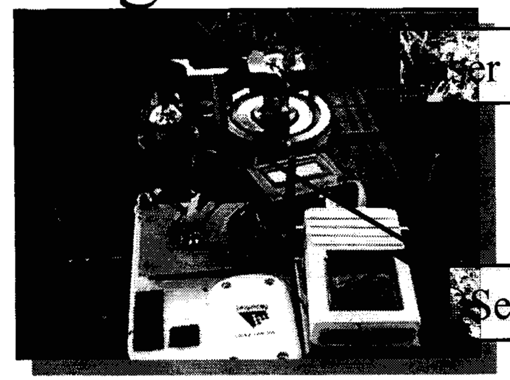
QuickTime™ and a
H.263 decompressor
are needed to see this picture.

Obstacle Detection in Vegetation

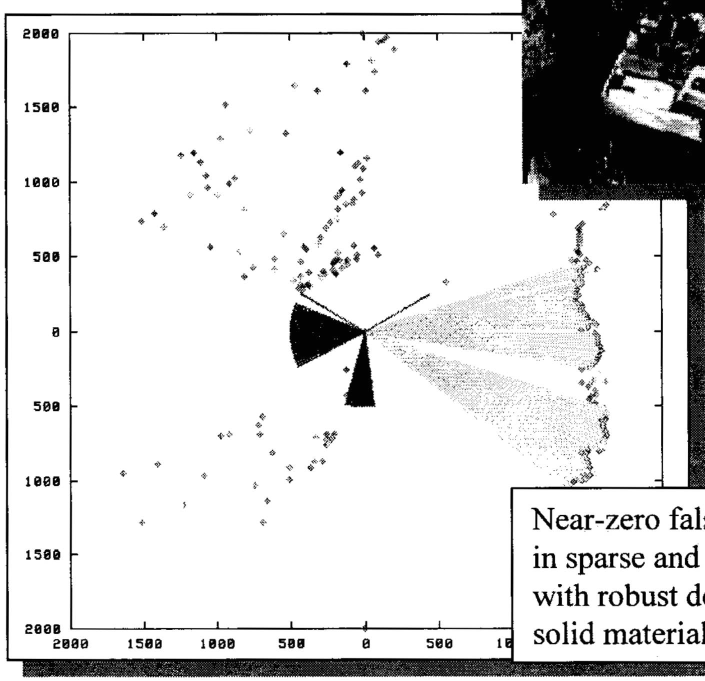
Goal: Remove vegetation effects from laser signal

Today: Very fast algorithm
Excellent performance in both sparse and dense grass

New: Object permanence over consecutive frames
classification = f(number of hits, size of obstacle)

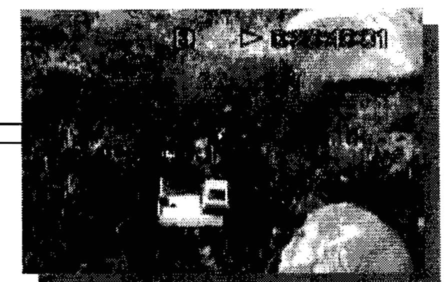


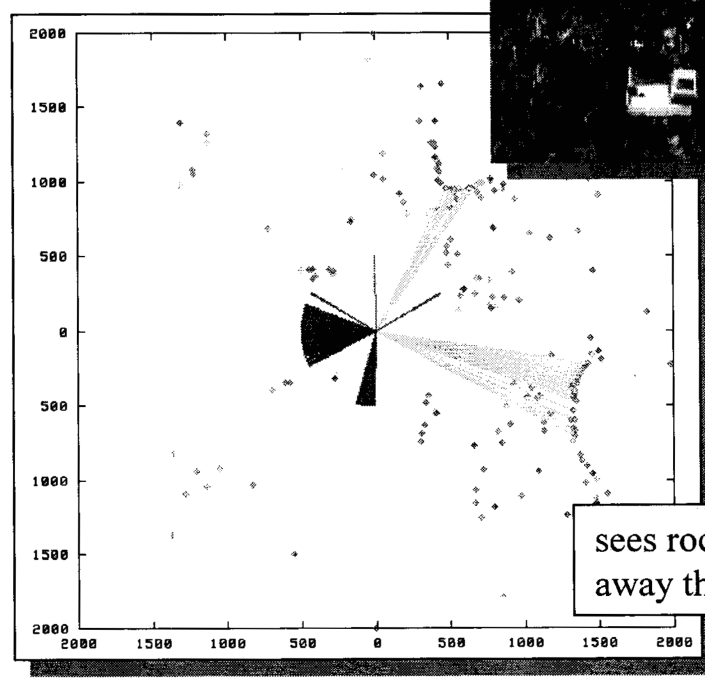
Ex. 1. Dense grass vs. ground



Near-zero false positives in sparse and dense grass with robust detection of solid material.

Ex. 2. Sparse grass vs. rock





sees rocks 1.5 m away through grass

Ladar in Sparse Grass with Rocks

QuickTime™ and a
Compact Video decompressor
are needed to see this picture.

Ladar in Dense Grass

QuickTime™ and a
Compact Video decompressor
are needed to see this picture.

Ladar Parallel to Dense Grass

QuickTime™ and a
Compact Video decompressor
are needed to see this picture.

Navigation in Vegetation

- No vegetation detection
- No obstacles

QuickTime™ and a
H.263 decompressor
are needed to see this picture.

Navigation in Vegetation

- Vegetation detection on
- No obstacles

QuickTime™ and a
H.263 decompressor
are needed to see this picture.

Navigation in Vegetation

- •Vegetation detection on
- •Obstacle in grass (person)

QuickTime™ and a
H.263 decompressor
are needed to see this picture.

Navigation in Vegetation

- Vegetation detection on
- Obstacle in grass (person)

QuickTime™ and a
H.263 decompressor
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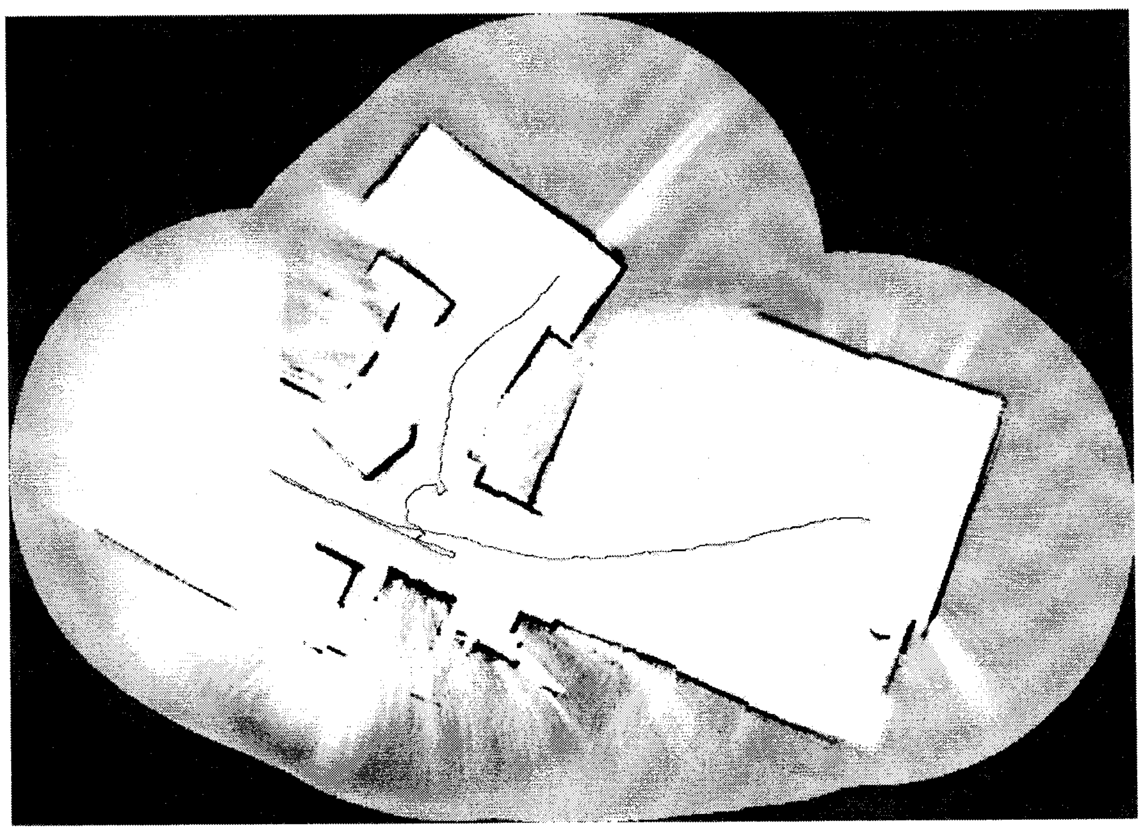
2-D Mapping

- Based on CMU code
- A picture file of the entire area Urbie has explored is reported back to the user



MER Autonomous Navigation Capabilities

Mark Maimone

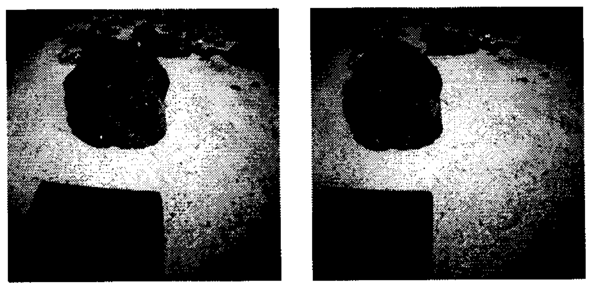
Machine Vision Group

MER

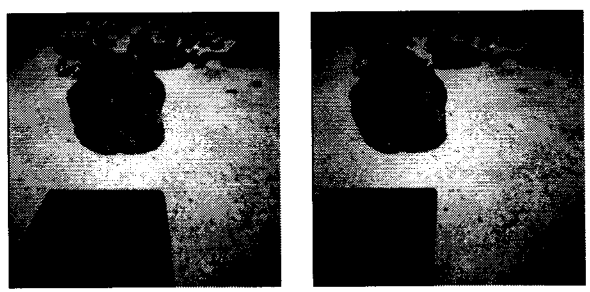
- NASA will launch two identical Mars Exploration Rovers to explore the Red Planet in the Summer of 2003
- To achieve the desired geologic diversity of measurements, the rovers must be able to explore up to 100 meters each day
- Human operators can typically plan no farther than 20 or 30 meters
- Therefore an *onboard autonomous surface navigation system* is being implemented

MER Stereo Cameras

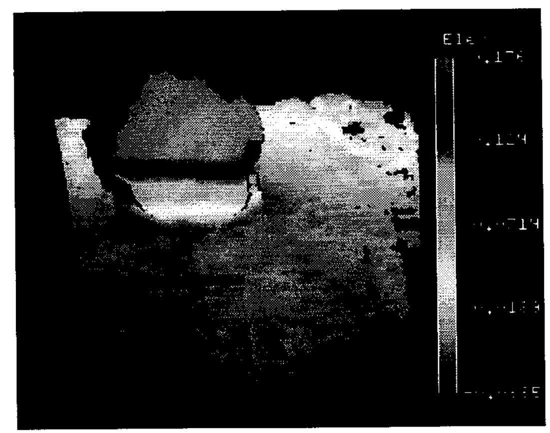
Raw
Images
(MER 1024x1024)



Rectified
Images
(MER 128x128)



3D Data, Colored to
highlight Elevation (Z)



MER Obstacle Avoidance

- **Stereo-generated range images are converted into an Elevation map (20cm x 20cm cells)**
- **Obstacles are found:**
  - **Step hazard**
  - **Rough terrain**
  - **Slope hazard**
  - **Missing information**
- **All arc paths are considered**
- **Paths leading toward the goal are preferred**
- **Path vote with highest value becomes drive command**

10 meters

Forward and Backward path votes