NIST Industrial Autonomous Vehicle (IAV) Project

Roger Bostelman
IAV Project Manager
(roger.bostelman@nist.gov)

Other Project Members:
Maris Juberts, Rick Norcross, Tsai Hong, Tommy Chang, Steve Legowik, Benoit Devos, Justin Osborn, Jucinda Moore, Patrick Conrad

Intelligent Systems Division
Manufacturing Engineering Laboratory
National Institute of Standards and Technology
Technology Administration
Department of Commerce

Presentation Outline

- From User's 2001: What we can/did do
- IAV Project Accomplishments:
  - Standards Efforts *(non-contact bumpers)*
  - Research and Development
    - Measurements
    - Advanced Technology
    - Support Example: Intellibot, Inc.
- Conclusions
- Next Steps

How ~~can~~ did we help?

(from ASRS/AGVS User's Conf. 2001 NIST presentation)

- Provide test procedures to back standard
  - e.g., similar to EN 1525 test part and placement
- Assisted MHIA,... with B56.5 "bumper" standard upgrade

- Participate in standards committee(s)
- Became a member ASME B56.5 Standards Comm.

- Provide measurement services to AGV industry
  - e.g., set-up a test course to test vendors vehicles, sensor config.'s, etc.
- No change (ready to test upon change to standard)

- Provide research and development toward measurements, standards, and advanced technology to help boost industry
  - e.g., vehicle navigation learned from military projects and transferred to industry
- Provided R&D toward measurements, standards, advanced technology ....

ASME B56.5a-1994 Standard
with regard to non-contact bumpers

8.10 Vehicle Emergency Controls and Devices

8.10.2 Mandatory emergency control functions and devices shall include the following:

(g) sensing device or combination of devices to prevent contact of the object sensed with the vehicle structure in the direction of travel.

Yet, call-out specifically for bumpers:

Definition: bumper - mechanically actuated device, which when depressed, causes the vehicle to stop

8.10.4 Bumpers: If used as emergency devices, bumpers shall not exert a force greater than ...

In '01/'02, NIST:

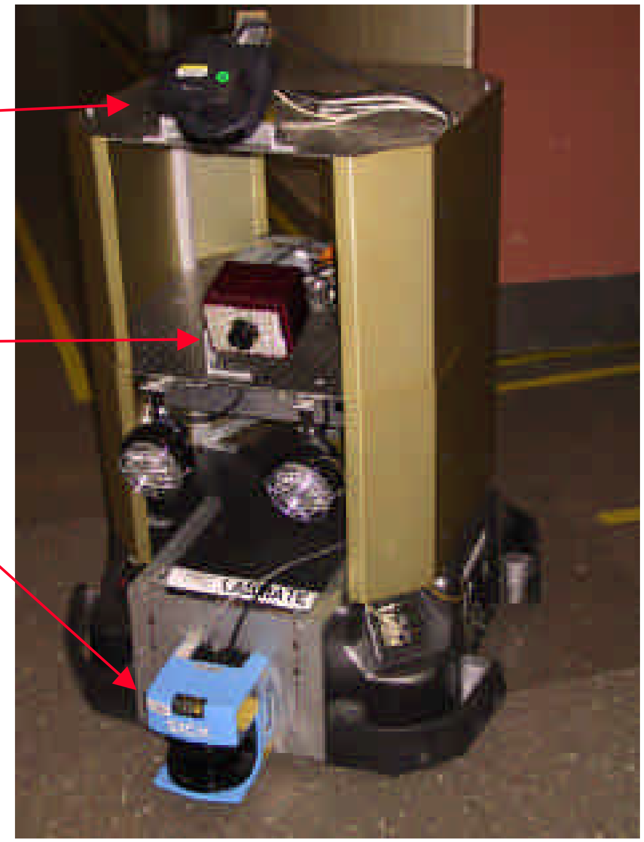
- Helped MHIA, AGV vendors to resubmit upgrade to this standard
- Persisted in bringing ASME together for a standards meeting (June 7, 2002 in Detroit)
- Outcome of meeting: next = draft change and resubmit

Measurements: *Sensors*

Toward AGV Advanced Sensors Applications

(i.e., smarter vehicles to do more):

- Transferred vision-guided lane/pattern-following from previous military/transportation mobility projects
- Advanced 2D Laser Scanner Accuracy
  - CSEM* Flash Ladar
  - Toward object recognition
- Verified Sick* Laser Scanner (Ladar) accuracy
  - 10 mm (±15 mm systematic error) within 1 to 8 m range *[Sick LMS 200 Technical Description Document]*
  - Found no algorithm or set-up to improve accuracy
  - Attempting to use "bumper" sensor for other purposes, i.e., vehicle docking, localization

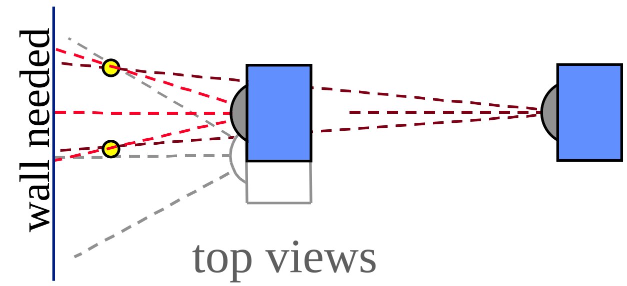


* NIST does not endorse products or vendors. The names mentioned are to adequately specify certain procedures and do not imply that they are the best available for this purpose.

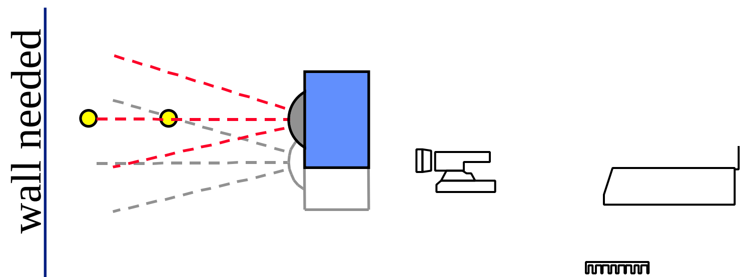
Measurements: *Toward More Sensor Applications with Laser Bumpers*

Vehicle bearing, localization using single scan-line Ladar (i.e., laser bumper)

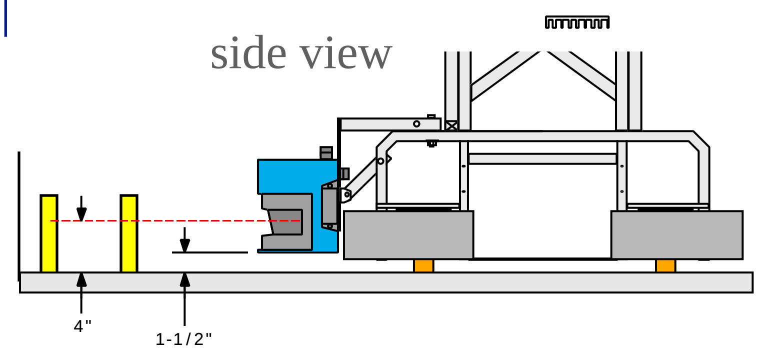
- Two posts (objects) w/known separation distance, location (**Good** - 0.13 deg or 1/16” @ 29” dist.)
  - fore/aft or side-by-side
- Can be used to *roughly* align sensor to object for:
  - Vehicle bearing (**Bad** - 4 deg @ 29” dist. - spot size)
    - e.g., if rear post appears left of front post, move vehicle right
  - Distance measurement (same as spec.)
    - Two known objects (tray table legs, door frame) to provide vehicle localization
    - Sensor spec.= 10 mm res., ± 15 mm error
- ***Next***: Vehicle docking using side walls
  - Using short walls (joining table legs), can determine vehicle position relative to table
  - Eliminate need to accurately align table initially or if moved



top views



side view



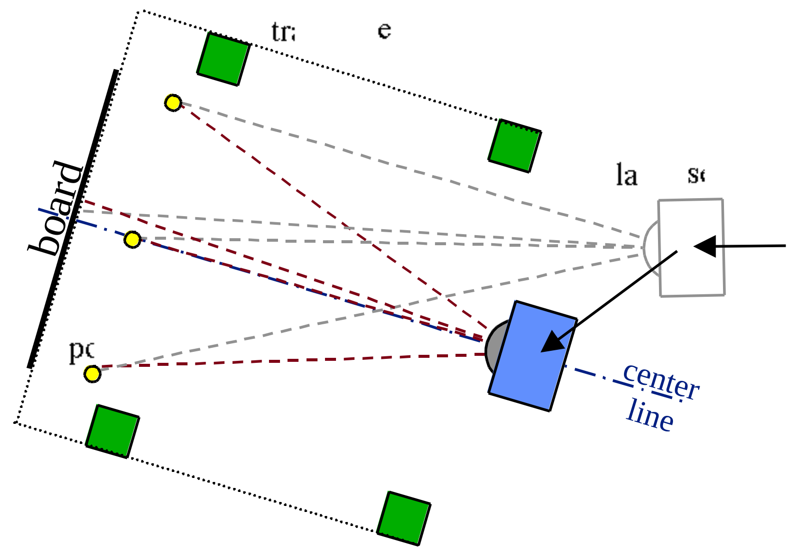
Measurements: *Toward More Sensor Applications with Laser Bumpers*

Vehicle Docking Experiment

- *Best dock scenario:* Three posts (or objects) w/known separation distance and a board

  (**Good** - 0.13 deg or 1/16" @ 29" dist.)

  - Worked well for vehicle dock to tray station
  - Eliminate need to accurately align to table initially or if table has moved
  - Opens opportunity to have flexibly positioned tray stations that move with workers instead of workers moving to tray stations.

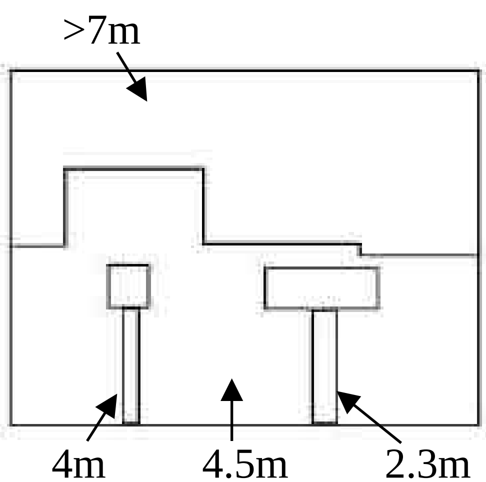


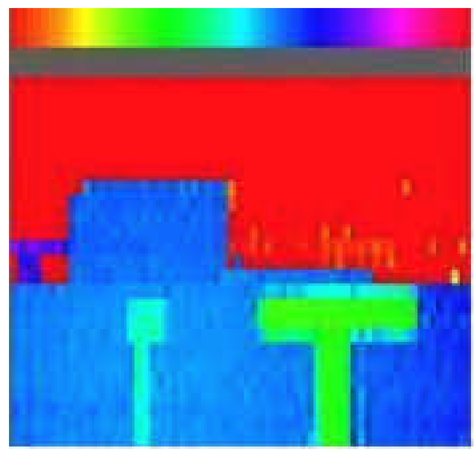
top view

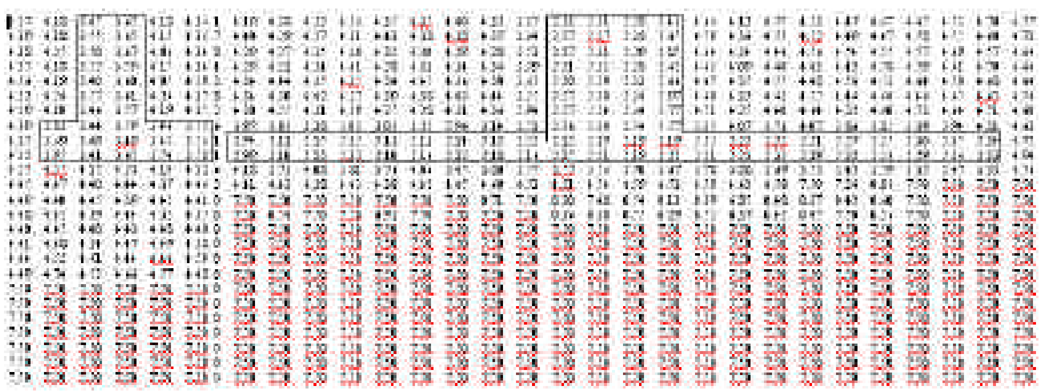
Measurements:

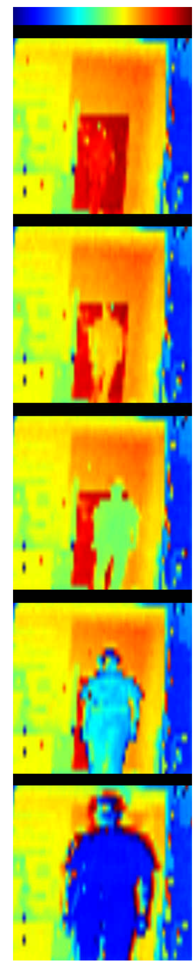
CSEM 2D Flash Range Sensor

Object recognition using 2D Flash Ladar Camera









Measurement method:
measures phase delay of modulated light reflected from target scene

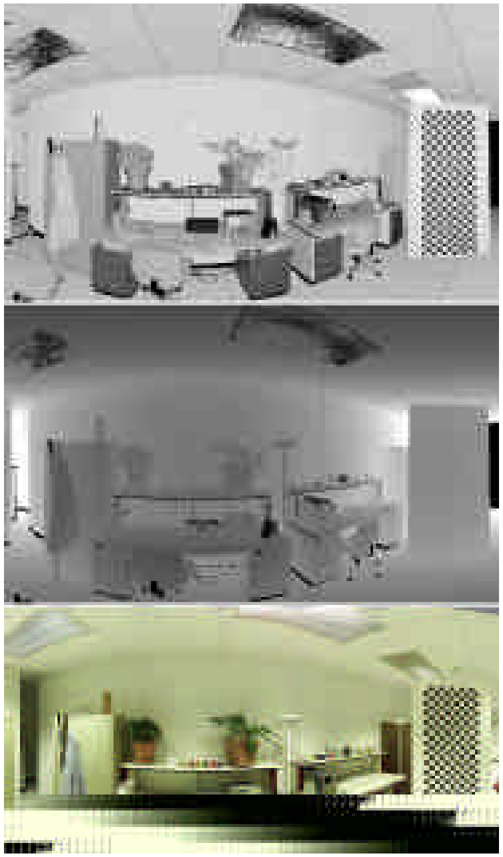
- 500 mW light source
- 25 x 64 pixel area camera
- 50 ms range measurement time
- 20 m current range
- +/- 2 cm range resolution

Future:
to reduce background illumination (sunlight) - replace led flasher with high power laser diode flasher

Measurements:

Example Advanced OTS Ladar Technology

Acuity Research, Menlo Park, CA



Intensity Image

Range image

Photograph

Advancements: Technology Transfer ***from*** Intelligent Control of Mobility Systems Program

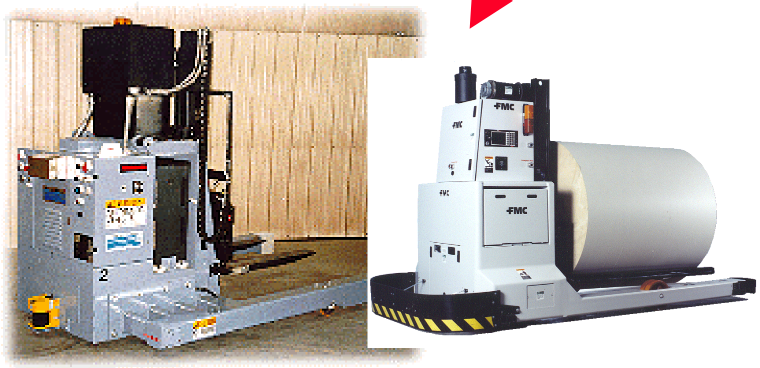
Military: Demo III Project (Army)

Transportation: Department of Transportation Project

Manufacturing: Industrial Autonomous Vehicles (IAV) Project

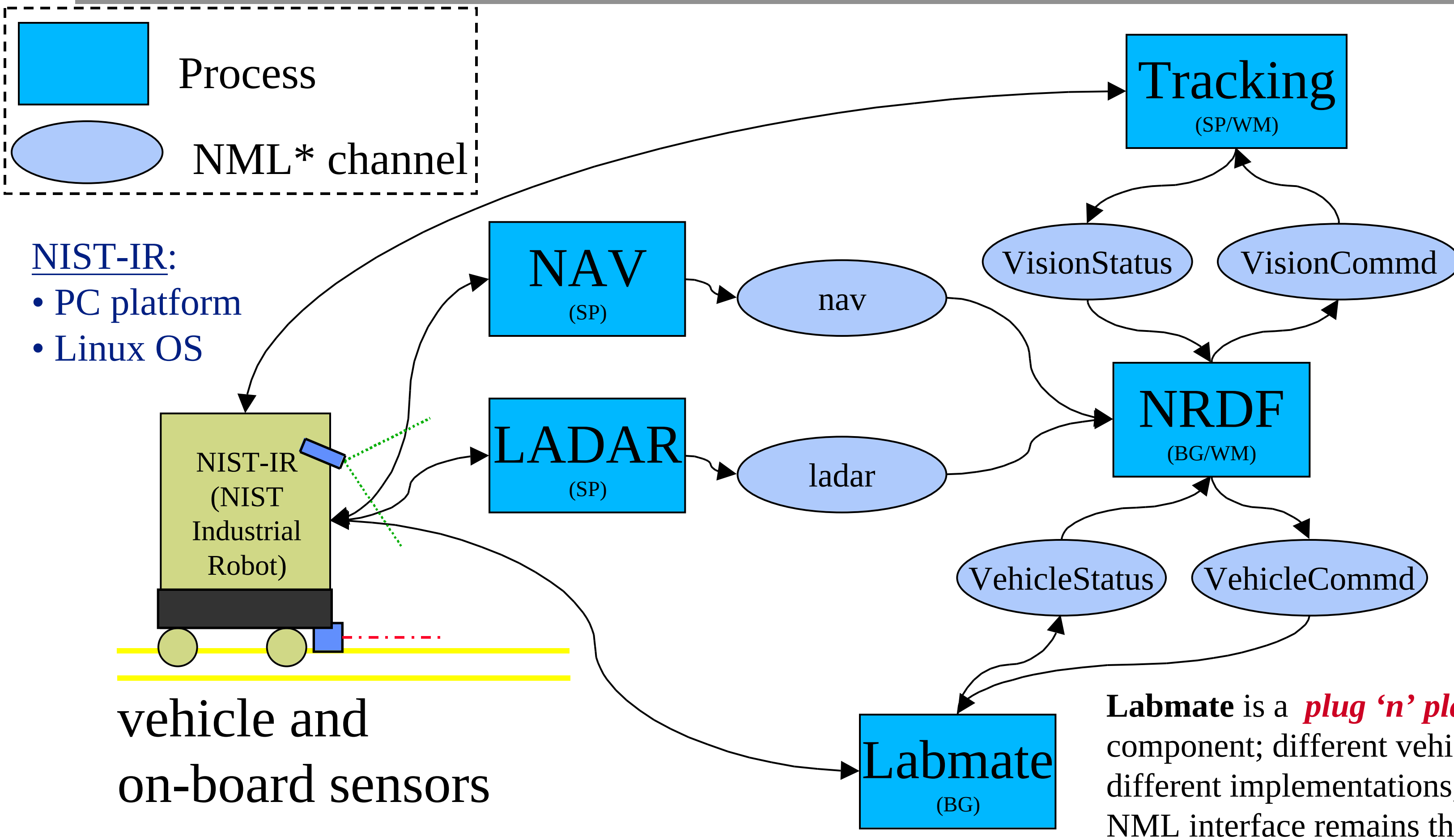
Project efforts in:
- standards,
- measurements,

and transfer of:
- advanced navigation technology



NIST-IR (IAV Testbed) Control Architecture

applied to lane-following, object detection



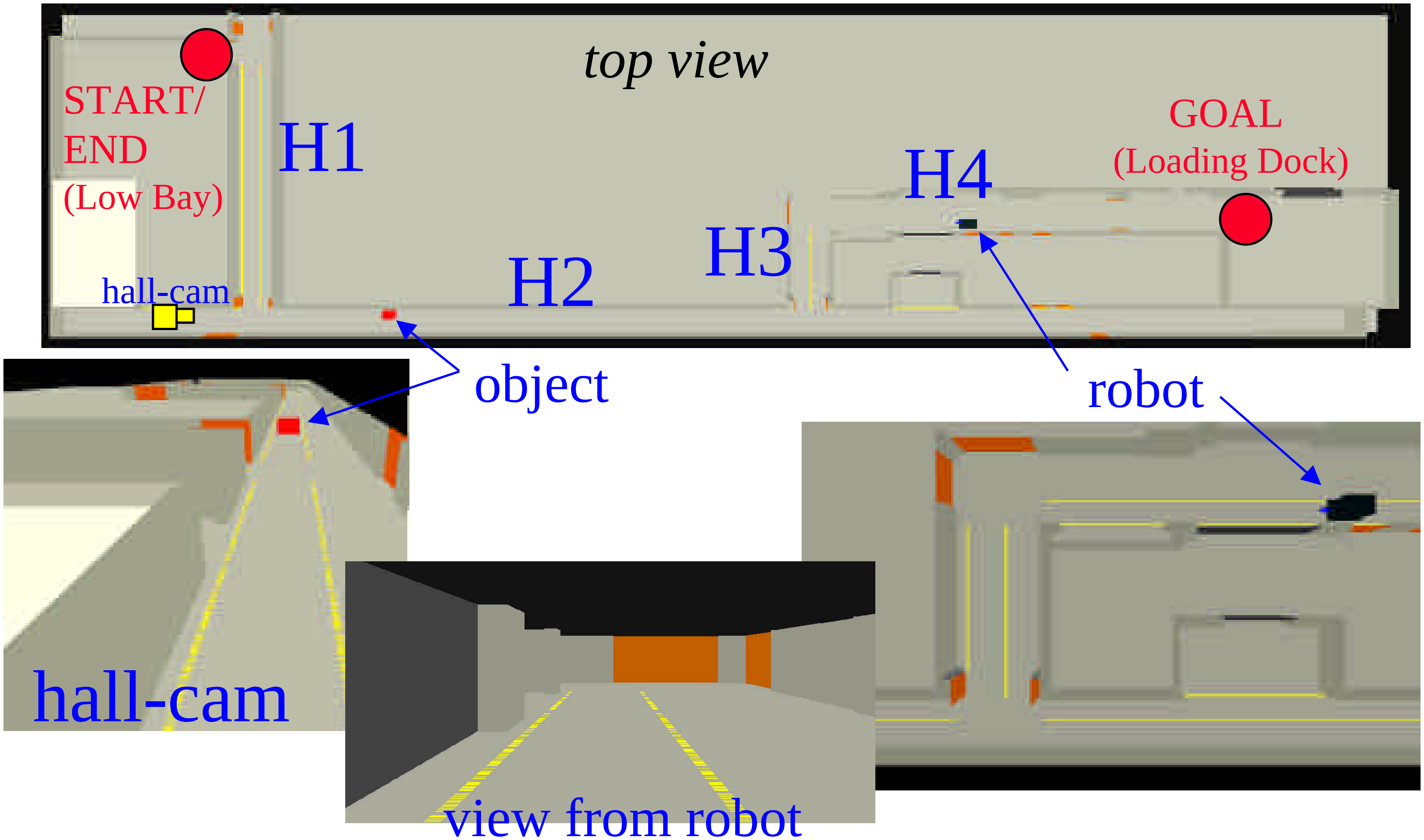
NIST-IR:
- PC platform
- Linux OS

Labmate is a ***plug 'n' play*** component; different vehicles have different implementations, but the NML interface remains the same.

**NML (neutral messaging language) provides a mechanism for handling multiple types of messages in the same buffer as well as, simplifying the interface for encoding/decoding buffers in neutral format and the configuration mechanism.*

NIST-IR Simulation (SimRobot-*freeware*)

facility model; used for path-planning development

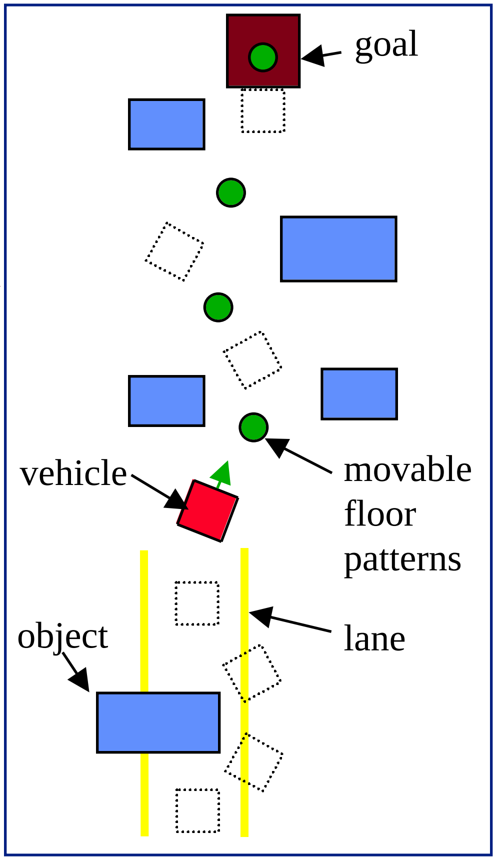


Advanced Technology
lane-following using vision, laser bumper

Vision-based, lane- and pattern-following toward autonomous vehicle adaptation to large, industrial facilities (e.g., Boeing Everett)

Industrial Vehicle Advancements

- **Lane/Pattern following using vision**
  - Follows tape lines or any (semi-) continuous feature
  - Can provide simple, rapid, inexpensive facility retrofit
  - Can provide even more capabilities:
    - Find goal (worker, tray-station, ... in unstructured area)
    - Lanes = highways; Floor patterns = unstructured navigation

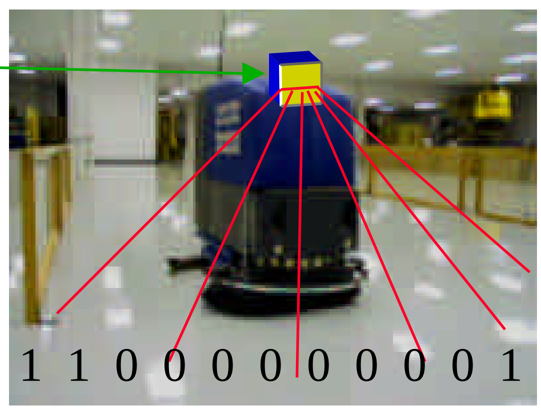


- **Obstacle detection using Ladar**
  - Not new but, maximize sensor capabilities to:
    - not need absolute positioning system
      - join Ladar info. with wheel encoders, camera for localization
    - dual-use Ladar sensing for bumper and vehicle docking
    - path planning: go around obstacles (out of taught path)
- **Can help decrease** AGV Users/Potential Users **capital investments** in vehicles, sensors, facility improvements, etc. **and increase profits** for AGV Vendors

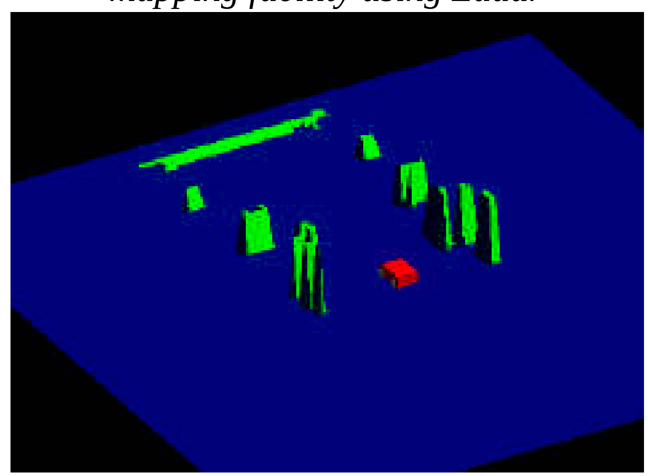
Direct Support Example: *Intellibot, Inc.*

- Signed a CRADA (Cooperative Research and Development Agreement) with Intellibot (formerly Servus Robots, Inc.)
- Designed and simulated Ladar-based obstacle detection and mapping system to adapt to floor-cleaning robots, etc.
  - Simple: scan, fill-in array of obstacles detected, report to robot controller
  - Potato chip racks in grocery stores, I/V poles in hospitals, etc.
- Next: test system on robot

Mount Ladar here



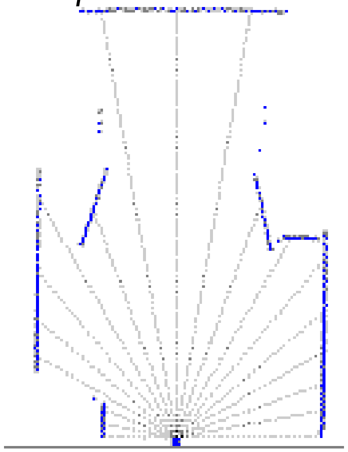
mapping facility using Ladar



Conclusions: *Several Accomplishments*

- Standards Efforts *(non-contact bumpers)*
  - Provided support for MHIA and vendors to allow non-contact bumpers across the industry
- Research and Development
  - Measurements
    - Existing and New Ladar technology evaluation
  - Advanced Technology
    - Plug-and-play architecture
    - Lane/Pattern following, *beyond* obstacle detection/avoidance
  - Direct Industry Support
    - Application of obst. det./mapping algorithm

data from Ladar sensor



vehicle nav. through glass corridor

Next Steps

- Host a Mini-Workshop including:
    - AGV Users, Vendors
    - Mobile Robot Researchers
    - Sensor Researchers
  - to suggest how to focus Federal Research funds
  - to discuss AGV/mobile robot advancements needed and problems encountered where NIST can provide solutions
- Report workshop findings to industry (user's and vendor's)
- Study new research areas for autonomous mobile robot applications (e.g., construction, shipyards, farming)
- Continue standards, measurements, and advanced technology efforts based on workshop findings, new research areas, and government/industry support