Integration and Evaluation of Sensor Modalities for Polar Robots

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Master's Thesis Defense

August 20, 2004

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Thanks

- Committee Members.
- PRISM faculty, staff, and students.
- NSF, NASA, KTEC, and the University of Kansas.

Overview

- Motivation
- Background and Related Work
- Sensor Suite for PRISM robot
- Sensor Integration
  - Hardware
  - Software
- Sensor Evaluation
- Future Work

Motivation

- Research in polar regions valuable to scientists
  - Determine impact of global warming and ice sheet melting.
  - Understand how the ice sheets play a role globally.
- Polar Radar for Ice Sheet Measurement (PRISM)
  - Radar system to measure ice sheet properties
  - Two radar systems
    - Monostatic/bistatic Synthetic Aperture Radar (SAR)
    - Wide-band dual mode radar
  - Radars towed by two vehicles
    - Human-driven tracked vehicle
    - Mobile robot

Motivation:

- PRISM Mobile Robot
  - Tows radar antenna for bistatic SAR
  - Built upon 6-Wheeled Max ATV mobile platform
  - Linear actuators for control
  - Sensor suite
- Goal:
  - Selection, integration, and evaluation of commercial off-the-shelf sensor modalities to support polar mobile robots.

Background – Navigation Sensors

- Position:
  - Dead reckoning
    - Approximates position based on rate of movement.
    - Shaft encoders, Doppler, accelerometers, etc.
  - GPS
    - Satellite-based beacons for triangulation
    - Three satellites required
    - 10 meter accuracy
  - Real-Time Kinematic (RTK) Differential GPS (DGPS)
    - Base station required
    - Four satellites required
    - Centimeter-level accuracy

Background – Navigation Sensors

- Heading/Orientation:
  - Compass
    - Less reliable near magnetic poles
  - Gyroscopes
    - Rate of rotation about an axis
    - Single or multiple-axis
  - Inclinometers
    - Dielectric fluid suspended between terminals
    - Roll and pitch

Background - Collision Avoidance

- Avoidance sensors
  - Machine Vision
    - Stereo vision
  - Sonar
    - Distance based on time-of-flight of ultrasonic pulse.
  - Laser Range Finders
    - Distance based on time-of-flight of laser-light pulse.
    - Scanning laser range finders
  - Millimeter-Wave (MMW) Radar
    - Obstacle distance and density

Background – Other Sensors

- Proprioception
  - Vehicle’s internal state
  - Fuel Sensors
  - Power Level Sensors
  - Internal Climate Sensors
    - Temperature
    - Humidity
- Outreach:
  - External Climate Sensors
    - Weather station
  - Video Camera

Background - Sensor Fusion

- Complementary sensor data
  - Merge data
- Contradictory sensor data
  - Select data with highest believability
- Tele-operation
  - Reduce amount of data presented to user
  - Reduces mental load of operator
- Numerous algorithms and approaches

Related Work - Planetary Rovers

- Challenges
  - No direct human intervention
  - No GPS available
  - Scientific payload has highest priority
- FIDO and SRR – *Jet Propulsion Laboratories*
  - Field Integration Design and Operation
  - Sample Return Rover
  - Design concepts for the Mars planetary rovers
  - Vision for navigation and obstacle detection
  - Sun sensor for heading

Related Work - Polar Rovers

- Challenges
  - Harsh environment: cold and wind
  - Unique obstacles
    - Crevasse, sastrugi, etc.
- Nomad – *Carnegie Mellon University*
  - Collection of meteorite samples in Antarctica
  - Stereo vision determined unreliable due to lack of surface contrast.
  - Utilized laser range finder and a prototype MMW Radar.
  - Differential GPS for position

Related Work - Polar Rovers

- Robot for Antarctic Surface – *ENEA*
  - Automated SnoCat tracked vehicle for travel between Antarctic camps
  - Vision for detection of previous tracks
  - RTK GPS for position
  - Accelerometers and inclinometers for orientation
  - Laser range finder for obstacle detection
  - Ground penetrating radar for crevasse detection

Sensor Suite - Position

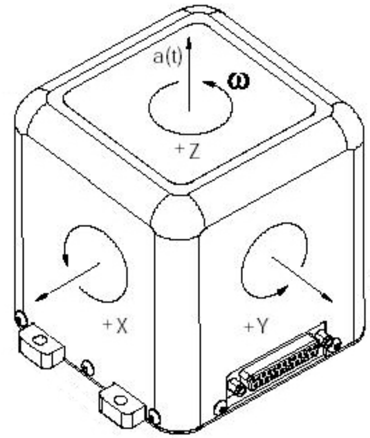
- Topcon Legacy-E RTK DGPS
  - Centimeter-level position accuracy
  - Uses GPS and GLONASS satellites
  - Radio data link with maximum range near 10km

Sensor Suite – Obstacle Detection

- SICK LMS221 Laser Range Finder
  - 80 meter range
  - Scans 180º field-of-view
  - 0.5º resolution
    - – Smaller obstacles may be undetectable at a distance
  - Internal heater and fog correction

Sensor Suite - Orientation

- BEI MotionPak II:
  - Three-axis rate gyro and accelerometer
  - Temperature sensor



- PNI Corp. TCM2-50
  - Tilt, temperature, compass, and magnetometer

Sensor Suite – Other Sensors

- Pelco Esprit Pan/Tilt/Zoom Camera
  - Camera with heated and pressurized enclosure

- Cruz-Pro TL30 Digital Fuel Sensor
  - Receives signal from fuel sensor inside a fuel tanks
  - RS-232 output

Sensor Suite – Other Sensors

- Rainwise WS-2000:
  - Temperature
  - Wind Speed
  - Wind Direction
  - Etc.

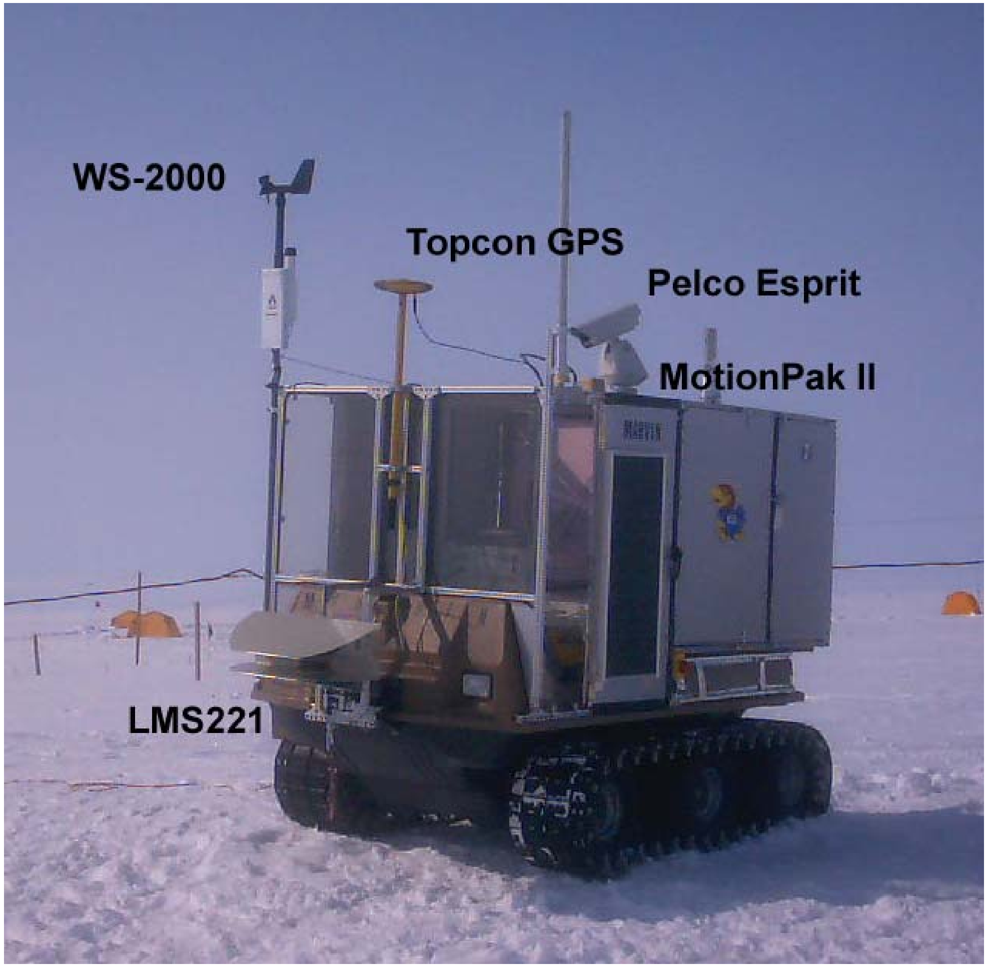
Hardware Integration: External

- Topcon GPS Antennas and WS-2000
  - Each pole mounted
    - – GPS needs clear view of sky.
    - – WS-2000 needs clearance for wind direction.
- Pelco Esprit
  - Mounted to center of rover's roof.
    - – 360 degree view.
- MotionPak II:
  - Mounted on roof at rotational axis.

Hardware Integration: External

- LMS221
  - Mounted to front of PRISM rover.
  - Configuration #1 - positive and negative obstacle detector
    - Height: 1.5 meters
    - Tilt: 10 degrees
    - Range: 10 meters
  - Configuration #2 - positive-only detector
    - Height: 0.5 meters
    - Tilt: 0 degrees
    - Range: 80 meters

Hardware Integration: External



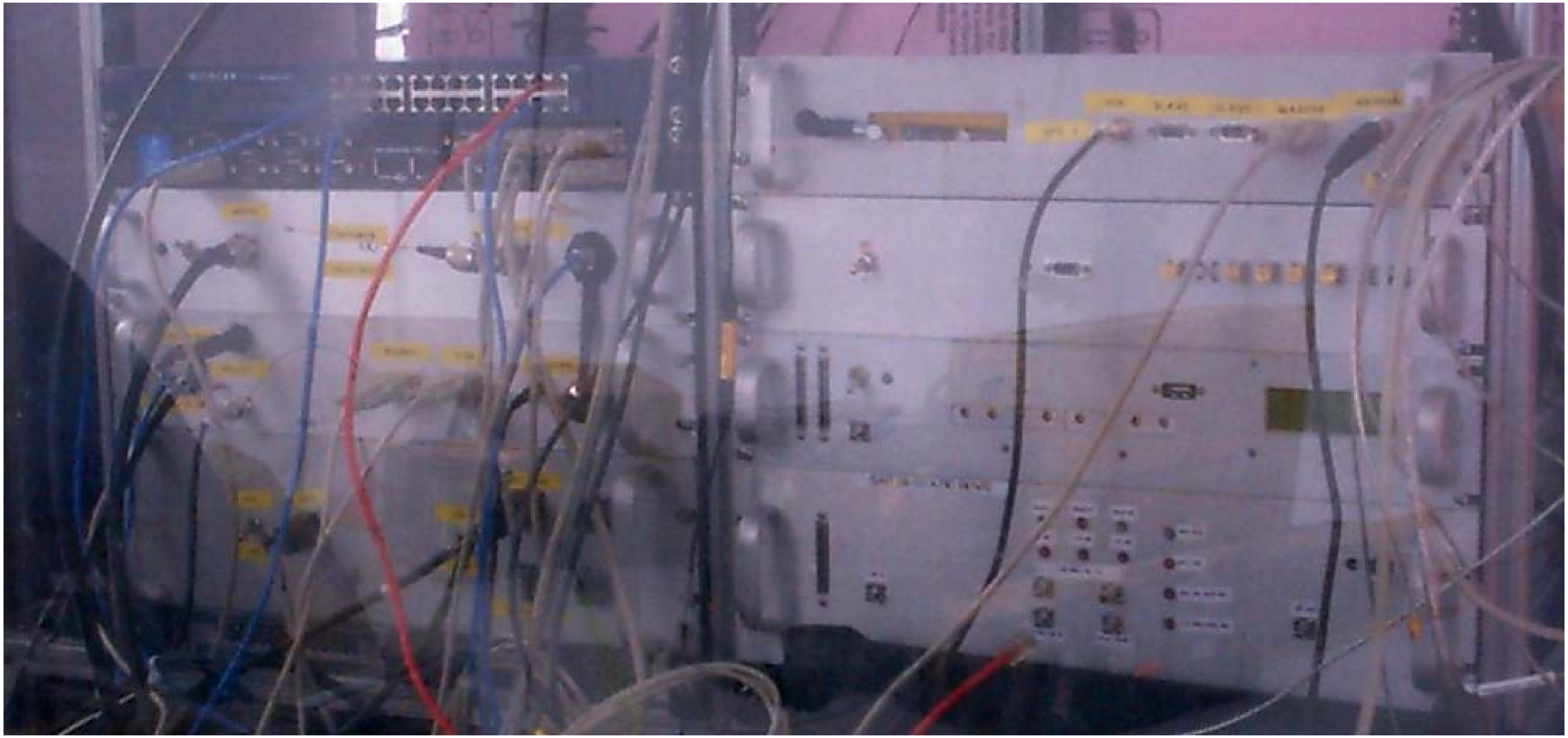
Hardware Integration: Internal

- Sensors placed in rack-mountable cases
  - Sensor case
    - TCM
    - Communication interfaces for external sensors
  - Power case
    - Power supplies for sensors and actuators
  - GPS Cases
    - Legacy-E receiver
    - Radio link

Hardware Integration: Connectivity

- Network Connectivity
  - Axis 2400 video server and computers
  - Netgear 24-Port Switch
- RS-232 Serial Connectivity
  - Each sensor (except Pelco) uses RS-232
  - Edgeport 16-port serial-to-USB hub
- Computing
  - Itronix GoBook Max ruggedized laptop

Hardware Integration: Internal



Software Integration – Sensor API

- Part of the PRISM robot API
- Java
- Interfaces written for generic sensor types
  - e.g. *BumpSensor.java*, *PositionSensor.java*, etc.
- Events and event listeners
  - Sensor error and update events are propagated to listeners
  - Listeners can add or remove themselves from a sensor's listener list

Software Integration – Drivers

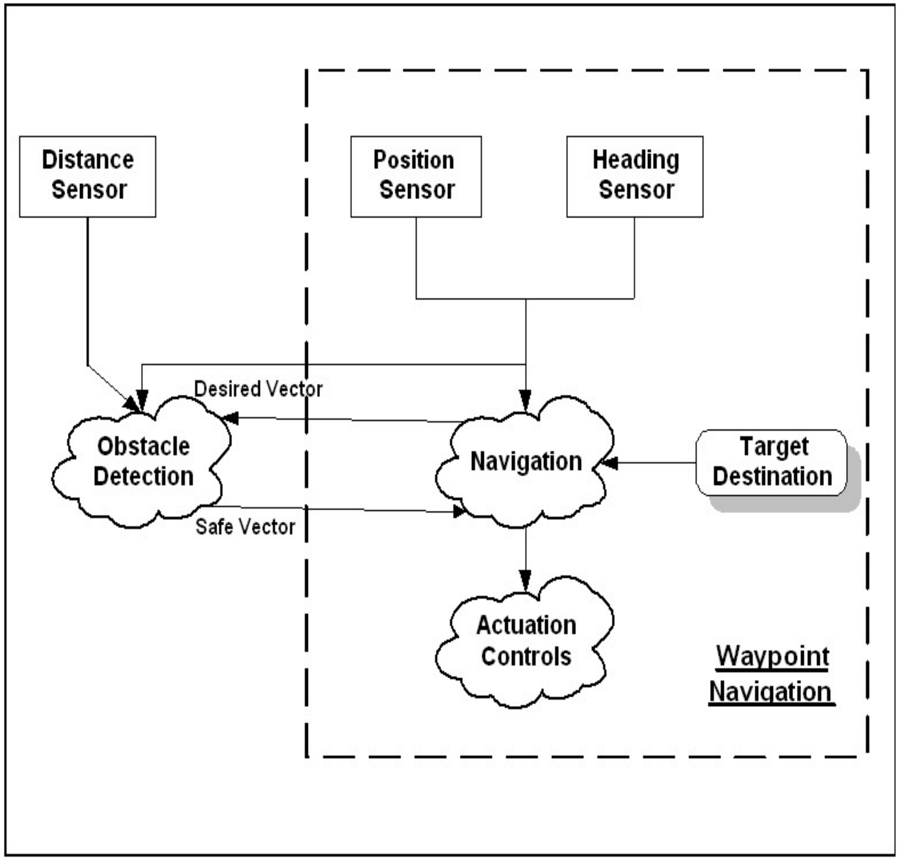
- Driver classes instantiate the API's base classes for each sensor in the sensor suite
- Several sensors implement multiple sensor interfaces:
  - e.g. TCM2 – *HeadingSensor*, *TiltSensor*, and *TemperatureSensor*
- Utilized manufacturers communication protocols
  - Datagram byte format
  - ASCII format

Software Integration – Fusion

- *Postion2HeadingSensor.java*
  - – Topcon GPS as a position sensor
  - – Cannot provide heading while turning in place
- *MarvinHeadingSensor.java*
  - Heading sensor data forwarded based on actuator state
    - – Actuator State = Turning
      - – Forward MotionPak II heading
    - – Actuator State = Not Turning
      - – Forward Position2HeadingSensor heading
      - – Calibrates MotionPak II

Software Integration – Fusion

- Waypoint Navigation
  - Initial autonomous mode of the PRISM mobile robot
  - Fusion of sensor data with actuation



Evaluation – Greenland Field Seasons

- Greenland 2003
  - North GRIP camp.
  - Rover and sensor survivability
  - Individual sensor tests and integrated data collection
- Greenland 2004
  - Summit camp
  - Radar integration and waypoint navigation
  - Collection of sensor data for future simulation

Evaluation – Climate Survivability

- Issues
  - Topcon GPS
    - Batteries proved unreliable
    - Replaced with power supplies
    - Generator for the base station
  - LMS221
    - Sun shroud necessary to reduce glare on scan window
  - WS-2000
    - Wind gauge became stiff in cold weather
    - Replaced for 2004 field season
- After resolving issues, all sensors now operate correctly in the harsh polar climate

Evaluation: GPS Relative Accuracy

- Relative Accuracy
  - Accuracy in the measure of distance between two points
- Two known locations required
  - National Geodetic Survey benchmarks
- Compared measured distance vs. known distance
- Relative Accuracy

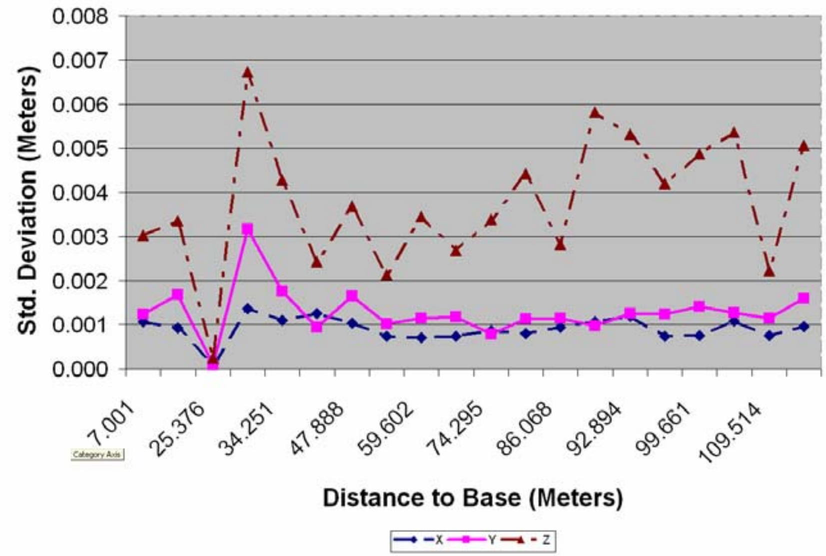
$x = 0.006 \pm 0.004$ meters

$y = 0.010 \pm 0.007$ meters

$z = 0.022 \pm 0.016$ meters

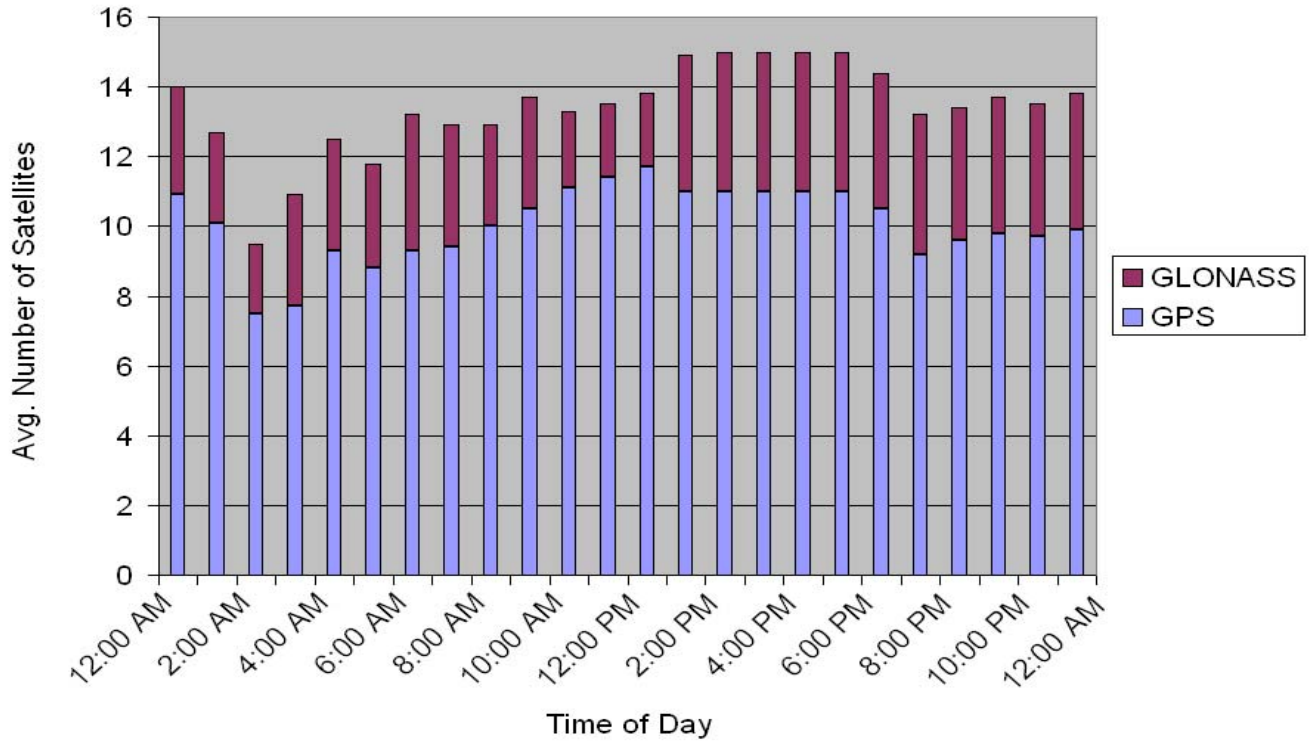
Evaluation: GPS Stability

- Calculated the standard deviation of measurements within 100 meters of the base station.
- Experiment requested by the PRISM radar team.



Evaluation: Visibility

- Measured number of GPS and GLONASS satellites available at the North Grip camp for a 24-hour period.



Evaluation – MotionPak II vs. TCM2

- Vibration and engine noise a major concern.
- Monitor sensor output over one minute and calculate the error accumulated
  - Sensor initially zeroed prior to data collection.
- No additional noise filters added
- Compare error at various levels of noise
  - No engine noise (ambient noise)
  - Rover engine noise (medium noise)
  - Rover and generator engine noise (high noise)

Evaluation – MP2 vs. TCM2

TCM2

Trial	Engine	Generator	Roll Error	Pitch Error	Yaw Error
1	off	off	0.026º	0.036 º	0.106 º
2	on	off	0.440 º	0.888 º	0.391 º
3	on	on	0.555 º	1.120 º	0.649 º

MotionPak II

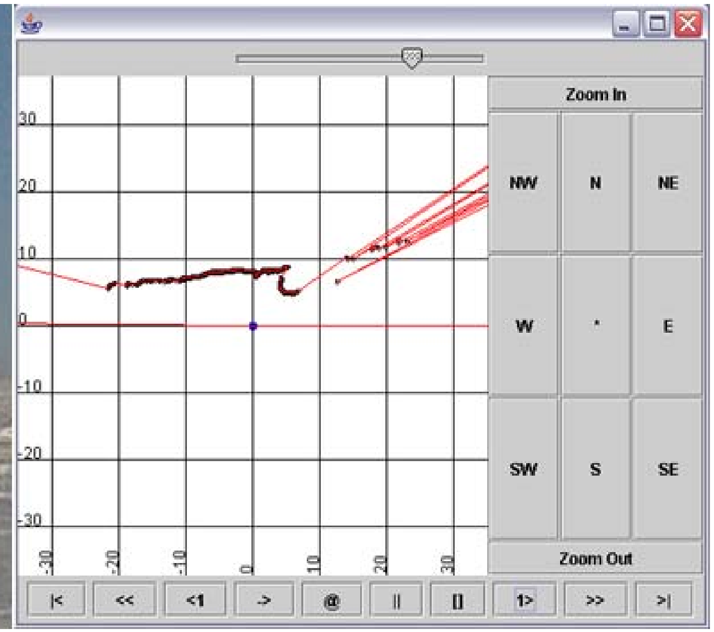
Trial	Engine	Generator	Roll Error	Pitch Error	Yaw Error
1	off	off	0.056 º	0.096 º	0.002 º
2	on	off	59.599 º	60.486 º	0.007 º
3	on	on	85.201 º	56.318 º	0.006 º

Evaluation: Obstacle Detection

- Test each configuration
- Distance for which obstacle first detected
  - Range
- Distance for which obstacles last detected
  - Peripheral vision

Evaluation: Obstacle Detection

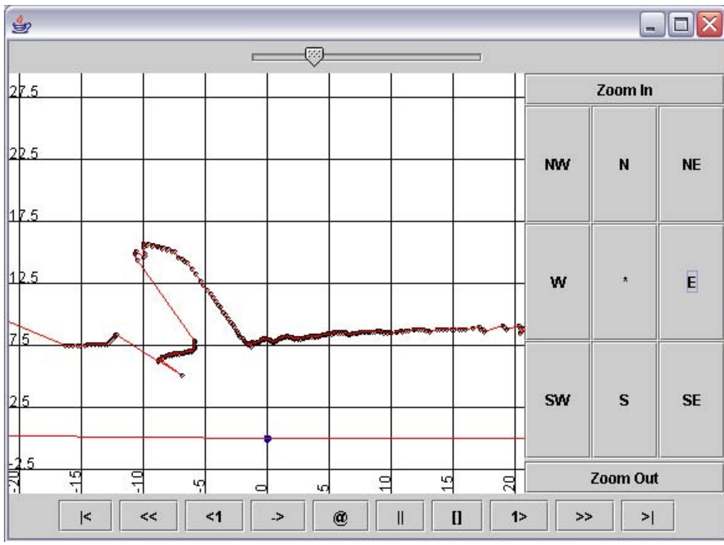
Configuration #1: Igloo



- First detected: 8 meters
- Last detected: 4 meters

Evaluation: Obstacle Detection

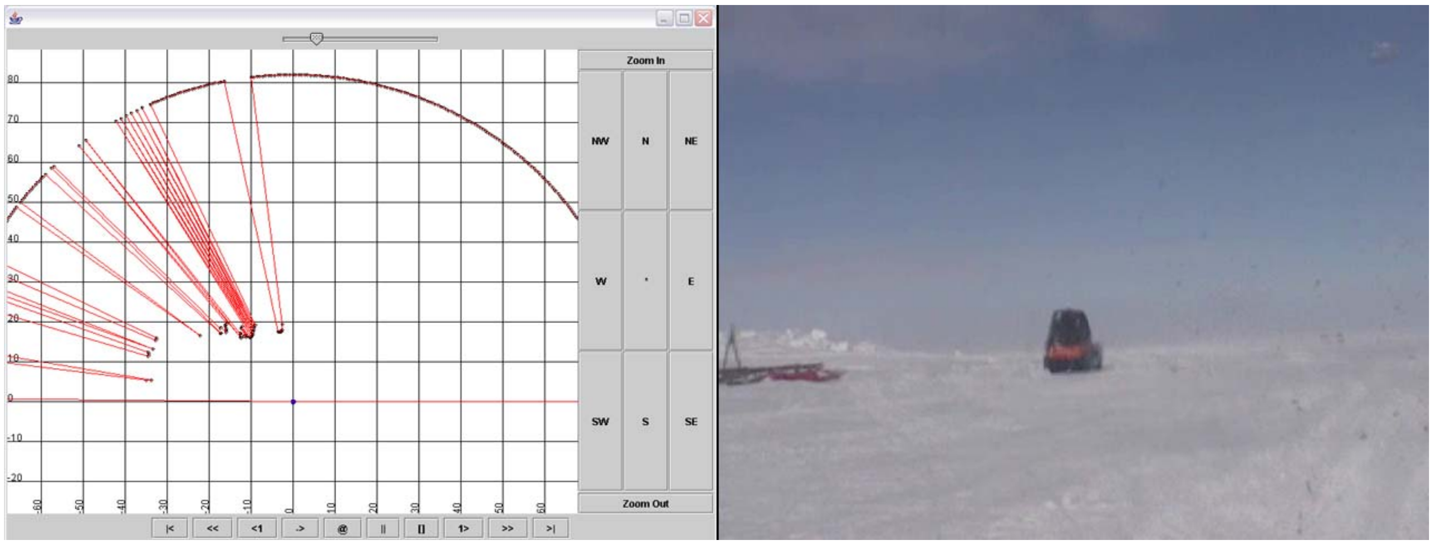
Configuration #1: Snow Pit



- As snow pit, obstacle detected at 10 meters
- As trench/crevasse, obstacle undetectable

Evaluation: Obstacle Detection

Configuration #2: Snowmobile

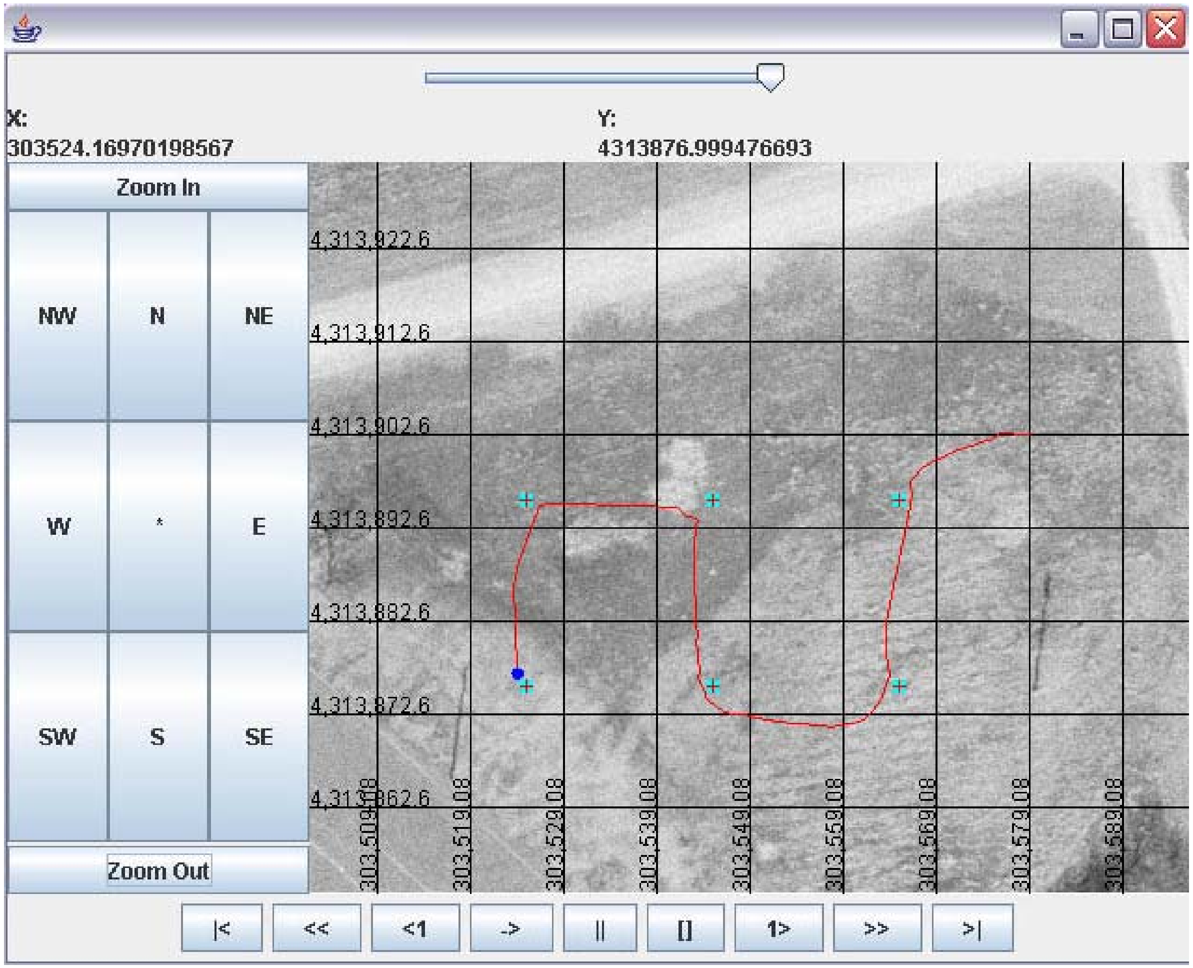


- First detect: 40 meters
- Last detect: 0 meters

Evaluation – Waypoint Navigation

- Waypoint Navigation
  - Demonstrates the integration of sensors, actuation, and platform.
  - Waypoints assigned in a pattern similar to its data collection pattern on the ice.
  - Thresholds:
    – Waypoint arrival: 1 meter
    – Heading on target: 10 degrees

Evaluation – Waypoint Navigation



Discussion

- Each sensor survives polar environment.
- Topcon GPS reliable with great accuracy.
- Noise filter needed for MotionPak II input.
- Laser range finder only viable for positive obstacles.
- Waypoint navigation using the sensors within the suite was accomplished.

Future Work

- Improve waypoint navigation precision
- Implement and test obstacle avoidance
- Additional software for fault tolerance
- Investigate the coupling of vision systems with existing avoidance sensors
- Further investigate
  - Data fusion techniques
  - Crevasse detection

Questions