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Evaluation of Candidate Millimeter Wave Sensors for Synthetic Vision.

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Evaluation of Candidate MMW Sensors for Synthetic Vision

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The goal of the Synthetic Vision Technology Demonstration (SVTD) Program was to demonstrate, and document the capabilities of current technologies to achieve safe aircraft landing, take off, and ground operation in very low visibility conditions. As part of the technology evaluation process, the Georgia Tech Research Institute (GTRI) was a primary participant in two of the major thrusts of the program: (1) sensor evaluation in measured weather conditions on a tower overlooking an unused airfield and (2) flight testing of sensor and pilot performance via a prototype system installed in a test aircraft.

GTRI supported tower testing of six different millimeter wave (MMW) radar sensor configurations and two infrared (IR) sensors at an instrumented tower facility at Wright-Patterson AFB in the 1991-1992 time frame. Sensors tested included a Honeywell 35-GHz MMW imaging radar, a Norden 95-GHz MMW target detection and tracking radar, a Lear Astronics 94-GHz MMW imaging radar, a 3-5 micron Kodak IR imaging camera, and a 3-5 micron Mitsubishi IR camera. The tower tests were performed under varied meteorological conditions including clear, fog, rain, and snow. As tower-test contractor, GTRI provided engineering services, including test planning, equipment preparation, field-test support, sensor data analysis, sensor performance modeling, and technical documentation of test results.

Three of the sensors evaluated in the tower tests were subsequently utilized in the flight-test evaluation program, which was performed during 1992 using a functional prototype SV system mounted in a specially configured Gulfstream II aircraft. During these flight tests, the observed performance of the prototype SV system was documented in actual and simulated weather conditions. The prototype system evaluated under this program included both a MMW radar sensor and an IR imaging sensor to detect and image the runway and surrounding area, as well as both a HUD and a head-down display to present the images and flight symbology to the pilot. GTRI's primary role in the flight test program was to perform analysis of raw radar data frames (snapshots). The effort focused almost exclusively on data snapshots captured by the Honeywell MMW radar. GTRI also participated in experiment design and test planning, characterization of the radar sensors, radar modeling, radar calibration, and weather data analysis.

The presentation first briefly addresses the overall technology thrusts and goals of the program and provides a summary of MMW sensor tower-test and flight-test data collection efforts. Data analysis and calibration procedures for both the tower tests and flight tests are presented. The remainder of the presentation addresses the MMW sensor flight-test evaluation results, including the processing approach for determination of various performance metrics (e.g., contrast, sharpness, and variability). The variation of the very important contrast metric in adverse weather conditions is described. Design trade-off considerations for Synthetic Vision MMW sensors are presented, and the presentation concludes with recommendations for future research to address the remaining unresolved issues.

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GTRI SVTD Support Program (1)

- Demonstrate capabilities of current technologies to achieve safe landing, take off, and ground operations in low-visibility conditions

- Major thrusts

  Sensor tower tests
    - Static Tests
    - Overlooking runway
    - Measured weather conditions

  Flight testing
    - Sensor and pilot performance
    - Prototype system installed in aircraft

GTRI SVTD Support Program (2)

- Tower tests: 1991-1992
  Radars: Honeywell 35 GHz pulsed
  Lear Astronics 94 GHz FMCW
  Norden 95 GHz pulsed
  IR: Two IR cameras
  Data Runs: 35 GHz (82), 95 GHz (174)
  Weather: Clear, rain, snow, fog

- Flight tests: 1992
  Radars: Honeywell 35 GHz pulsed
  Lear Astronics 94 GHz FMCW (limited)
  IR: Kodak 3-5 mm focal plane camera
  Approaches: 35 GHz (96), 94 GHz (11)
  Weather: Clear (46), fog (41), snow (8), rain (1)

Data Analysis & Calibration (1)

- Calibrate MMW Sensors
  - Measure radar system gains and losses
  - Inject RF signal to develop receiver transfer function
  - Locate calibrated reflectors within runway scene
- Reduce Radar Sensor Data
  - Convert raw data into equivalent received power
  - Extract values from areas of interest within scene

Data Analysis & Calibration (2)

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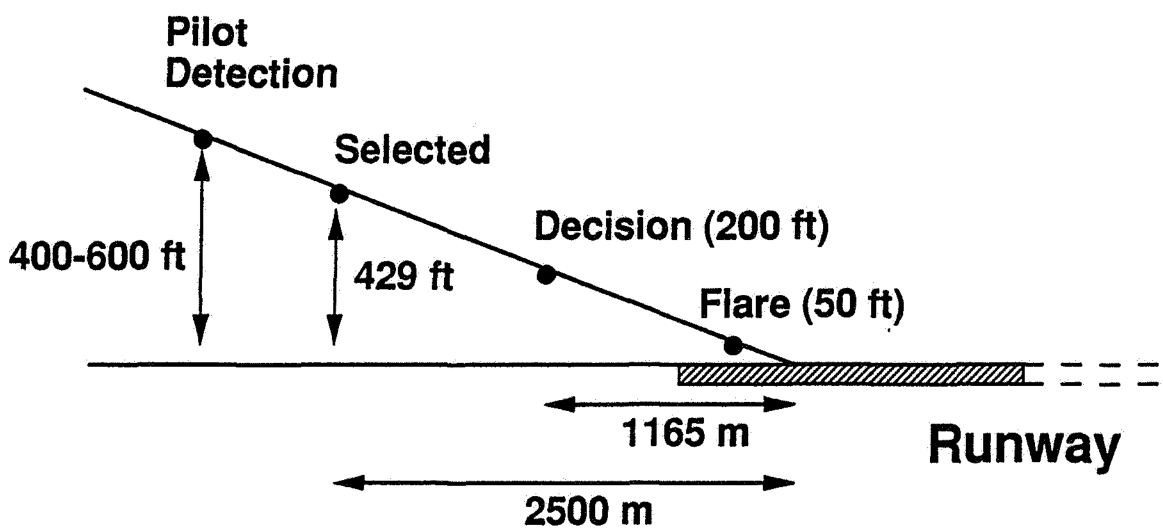
- Develop Sensor Figures of Merit
  Contrast, sharpness, and variability

- Calculate Radar Phenomenology Values
  RCS for runway and bordering grass
  Volumetric RCS and path attenuation for precipitation

Flight Test Data Analysis Methodology (1)

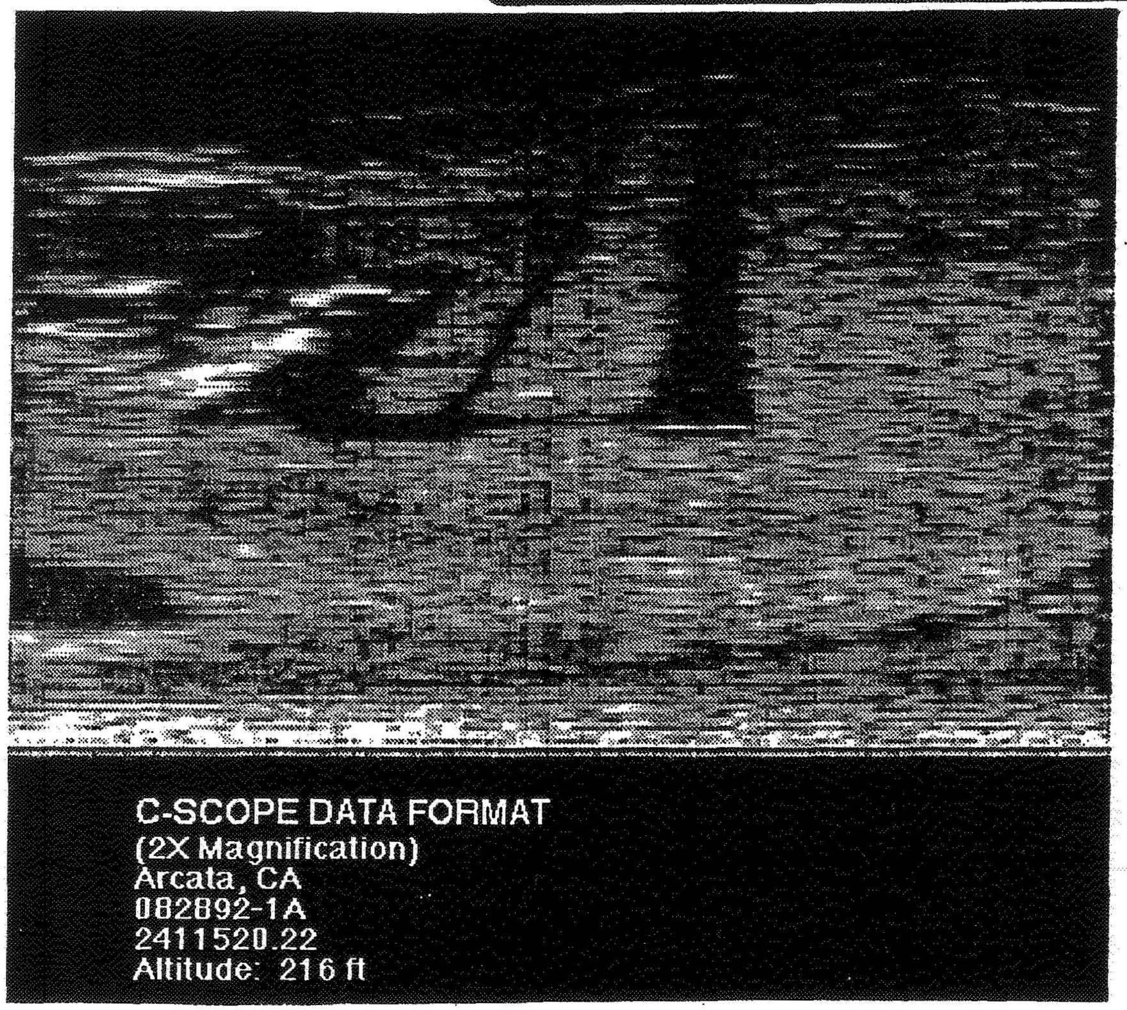
- Analyze discrete radar snapshots (full azimuth scan) at selected ranges



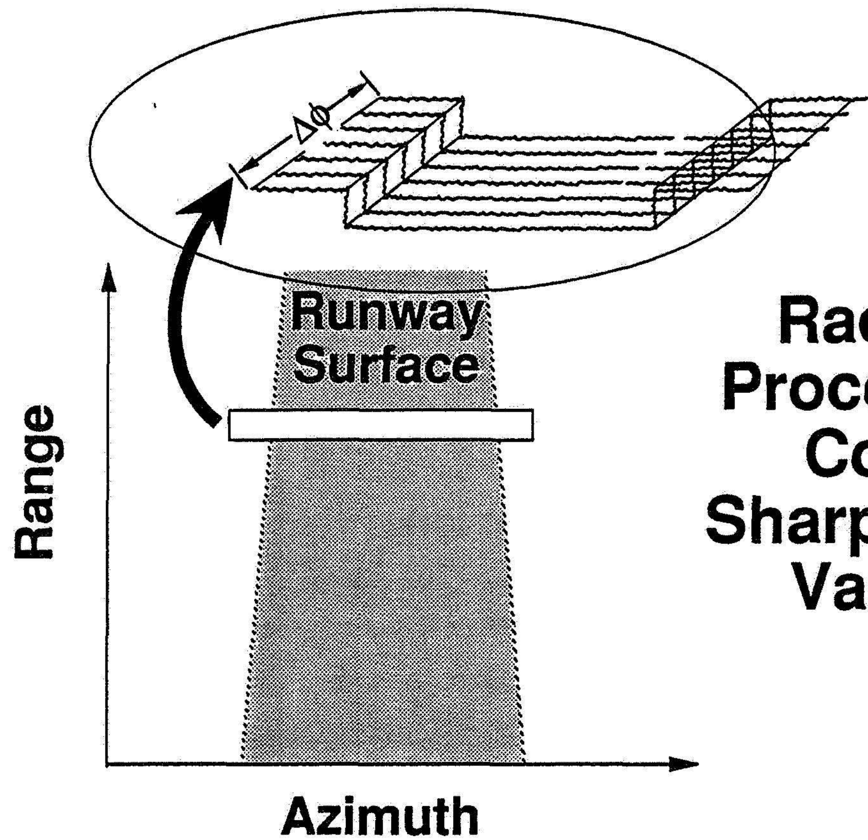
Flight Test Data Analysis Methodology (2)

- Weather data
  - Water drop size distributions
  - Liquid water content (LWC) for fog
  - Rainfall rate
  - Equivalent rainfall rate for snow
- Airport ground truth
  - Runway description
  - Terrain description
- Radar calibration
  - MMW Receiver calibration
  - Radar reflectors at selected runways

MMW Sensor Evaluation

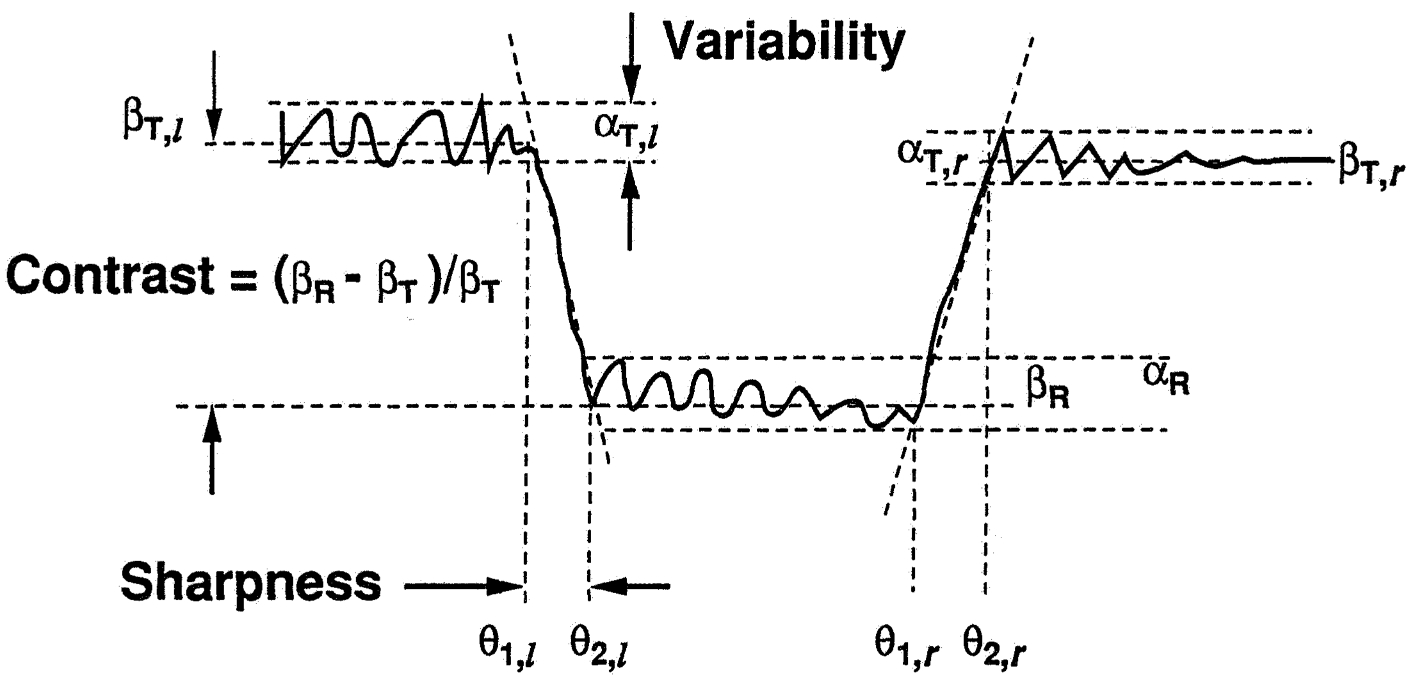


MMW Sensor Evaluation



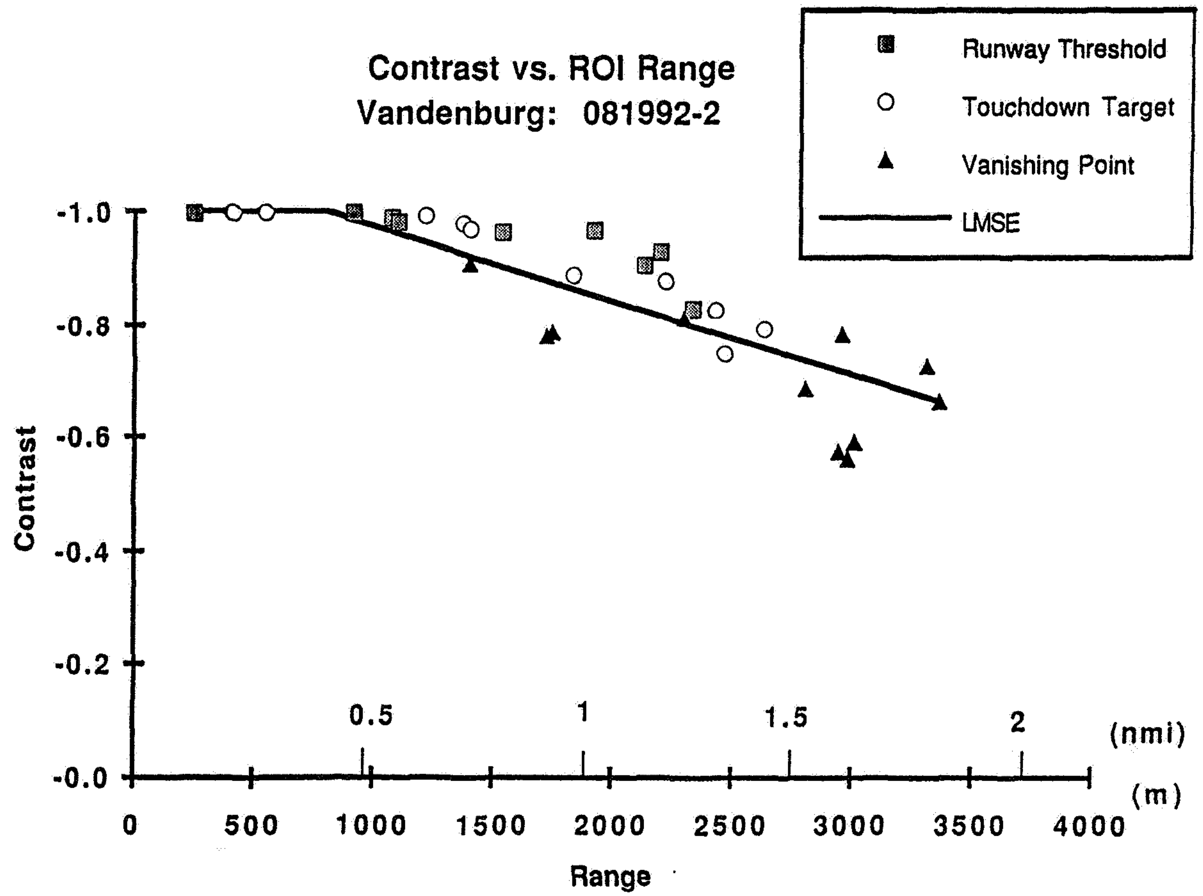
Radar Data Processing for Contrast, Sharpness, and Variability

Definitions of Contrast, Sharpness, and Signal-to-Variability Ratio



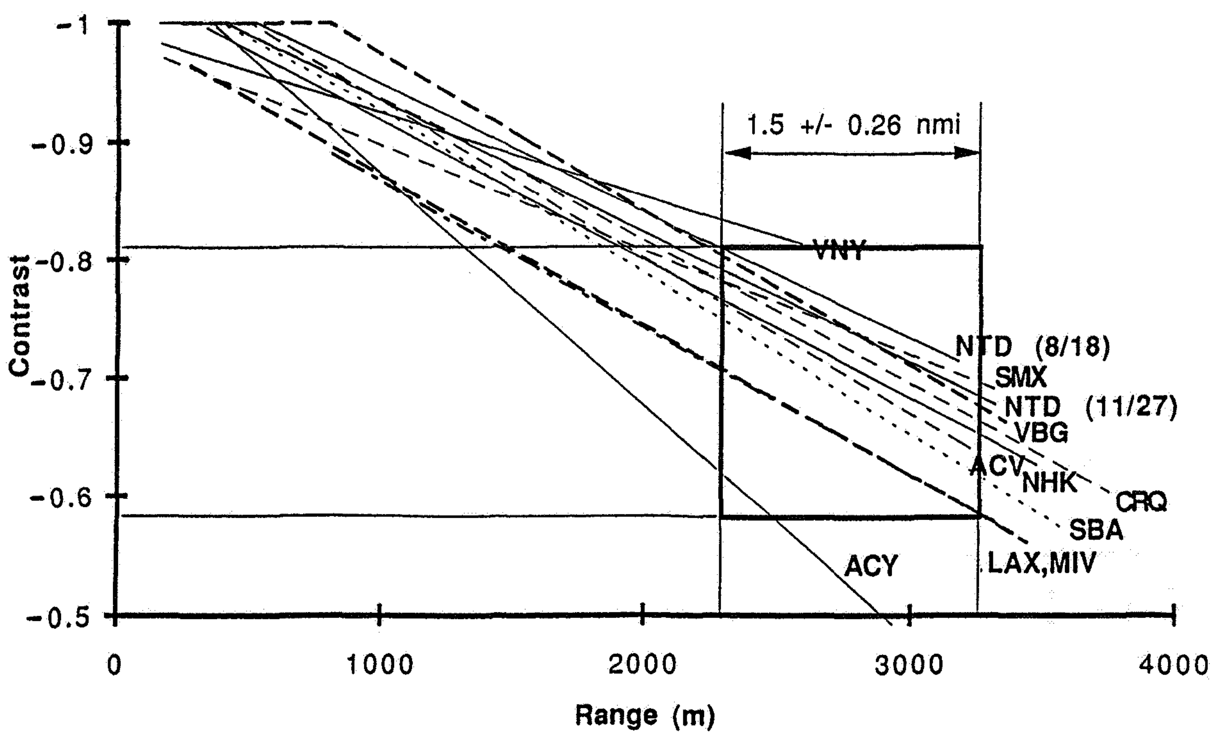
SVS Technology Demonstration

MMW Sensor Evaluation



MMW Sensor Evaluation

Contrast vs. ROI Range
Clear Weather Approaches



Weather Effects on Contrast (35 GHz)

- Fog
  - Excellent weather penetration (no effect)
  - (Most delays due to fog)
  - (Greatly reduced visual range)
- Rain
  - Poor penetration for rain rates > 8 mm/hr
  - Drop size distribution dependence
  - (Visual range reduction in very heavy rains)
- Snow
  - Falling snow not a problem
  - Accumulated snow effect significant
  - Runway must be cleared to improve contrast

Design Tradeoff Issues (1)

- MMW Band
  95 GHz: higher az resolution for given aperture
  35 GHz: superior weather penetration

- Azimuth and Range Resolution
  High res (0.3° az by 7 m range): sharper images
  Low res (1° az by 20 m range): higher contrast

Design Tradeoff Issues (2)

- Antenna Scan Rate
  High rate (10 Hz): reduced image update latency
  Low rate (5 Hz): more dwell time for integration

- Antenna Polarization
  Circular: reduced rain backscatter/better image
  Linear: higher return from grass clutter

Future Research Needs

- Use SVTD data to predict performance of future candidate MMW sensors
- Develop better models for performance of MMW sensors in weather
- Validate performance of future candidate MMW sensors based on the test and evaluation methodology established in the SVTD program
- Refine image quality metrics
- Examine techiques for image enhancement