Robotics and Automation Applied to Caltrans Highways

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A partnership between the
University of California - Davis
and the
California Department of Transportation

Robotics

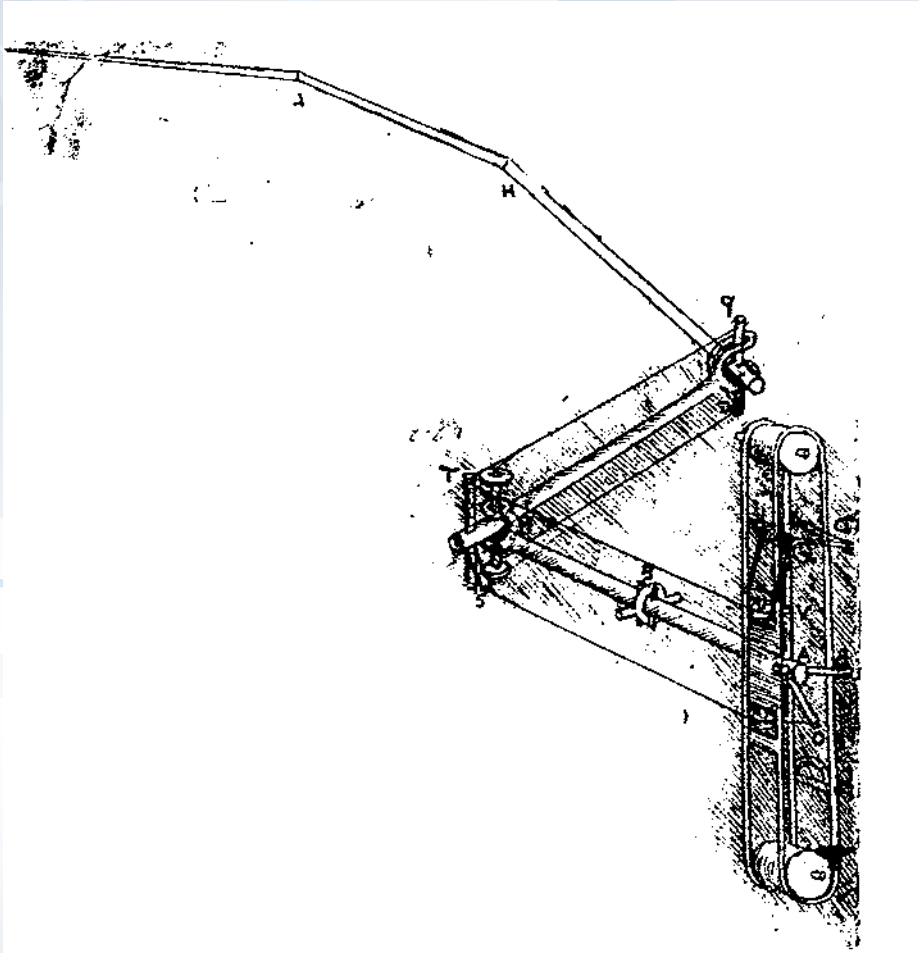
- Concept of robotics goes back to antiquity
- Early mechanical robots can be traced to pre-industrial revolution
- Modern terms and concepts were first introduced in Theatrics and Fiction
- The field has evolved due to integration of computing, sensing, communication, and mechanical design technologies
- Much of the developments have occurred after World War II and since 1950's

Antiquity and Robotics

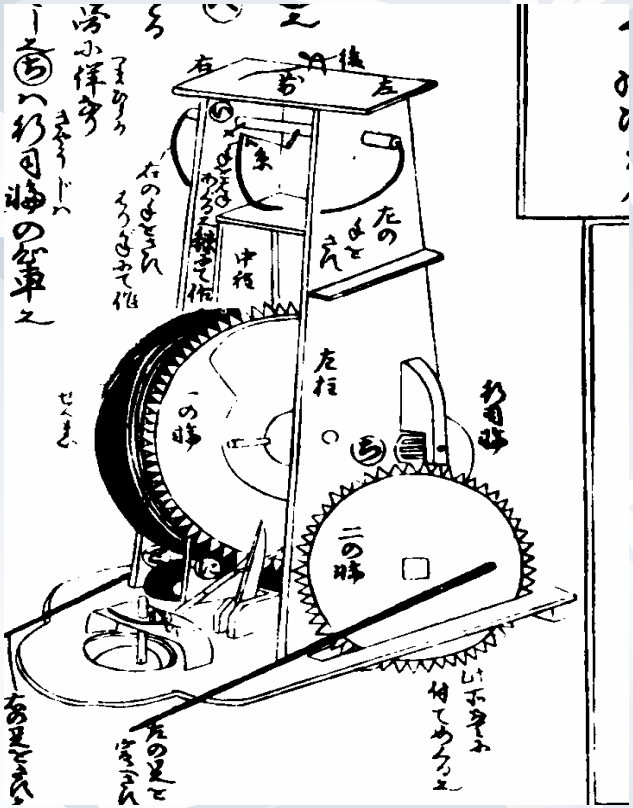
- In the 18th book of Iliad (8th century B.C.), Homer describes servants that are built by Vulcan for the service of Gods.

- These use wheels for mobility, are human shaped, are able to speak, and have some intelligence.

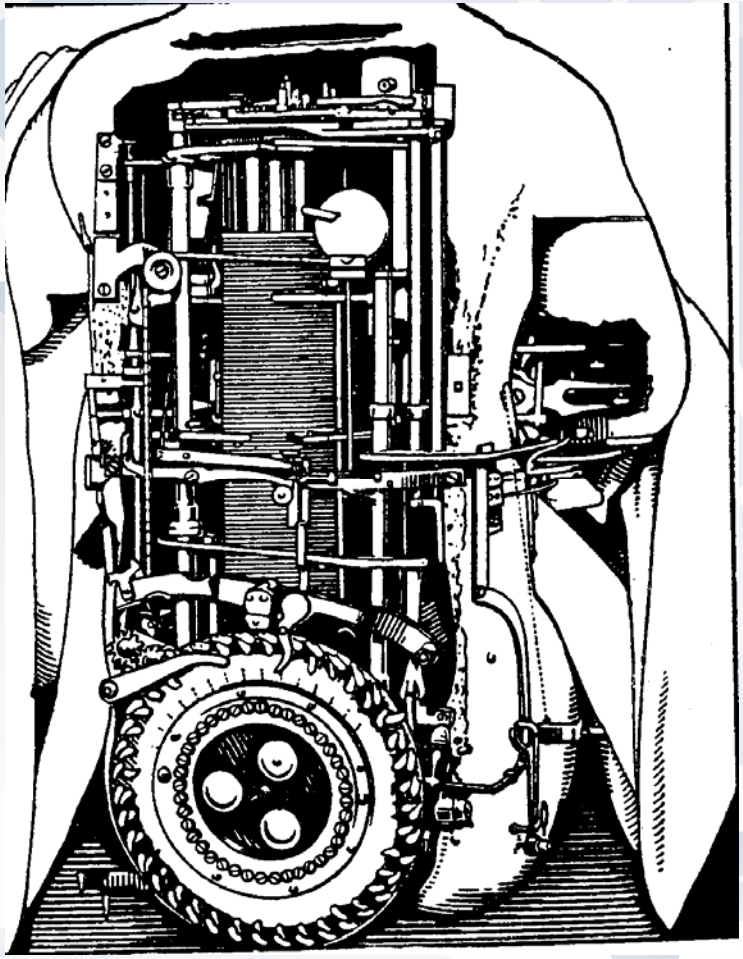
Leonardo da Vinci's Wing (15th Century)



Japanese Maid (17th Century)

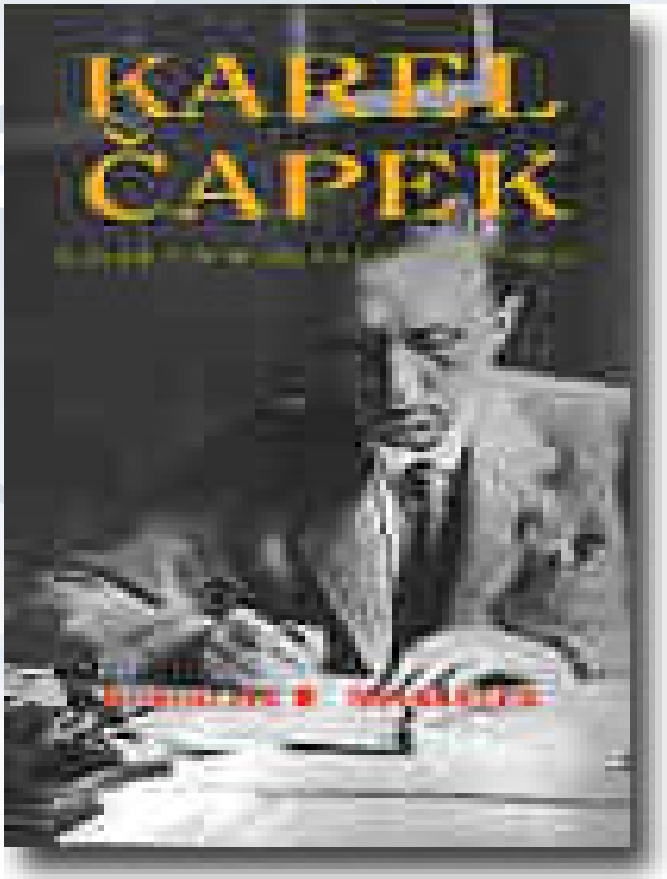


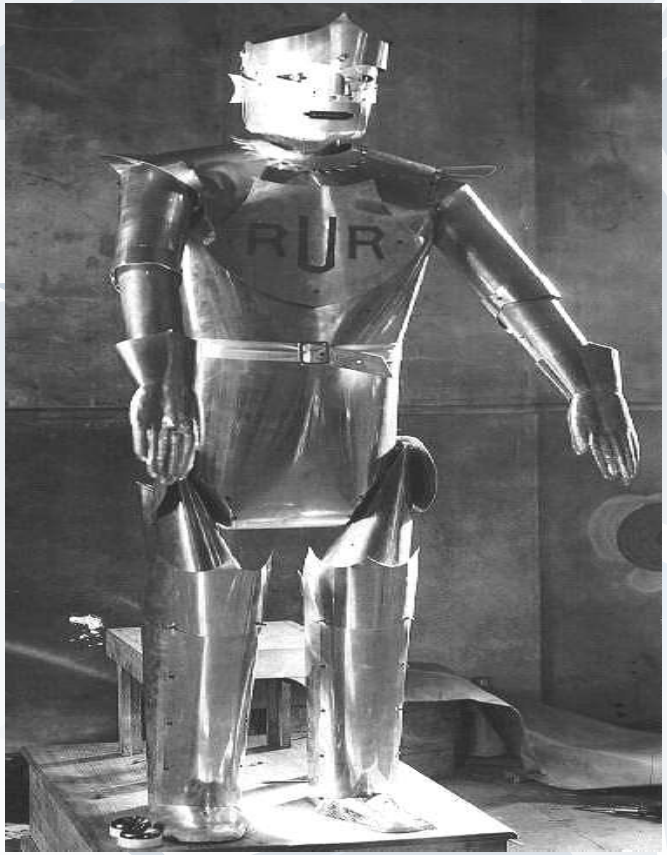
Automatic Writer by Jaquet-Droz in 1760



Terminology

- The Word *Robot*:
  - From Czech word Robota for forced labor or compulsory service
  - 1st appeared in “Rossum’s Universal Robot” (R.U.R) a Czech play by Karel Capek ((pronounced “chop’ek”)
  - R.U.R opened:
    - Prague 1921, New York 1922, London 1923
- 1920 translation by P. Selver available as Penguin series from Dover
- More recent translation is contained in translation of a collection of Capek’s writings called Towards the Radical Center.


KAREL
ČAPEK


RUR

Terminology

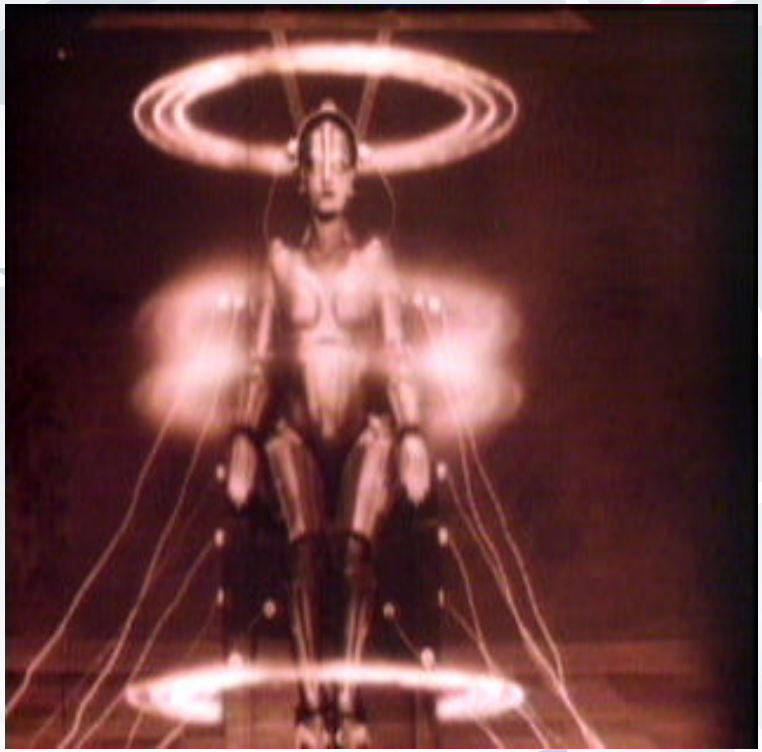
- Isaac Asimov (1920 – 1992) introduced the term robotics in his story Runaround published in 1942.
- Asimov is credited with popularizing the concept of robotics through a series of short stories about robots starting with a story called “A Strange Playfellow” which he wrote for Super Science Stories magazine.
- This story is about a robot and its affection for a child that it is protecting. He later renamed this story calling it “Robbie”.
- Asimov generated many other stories about robots which are compiled into a book volume called “I, Robot” published in 1950

Asimov

- First Law: A robot may not injure a human being, or, through inaction, allow a human being to come to harm.
- Second Law: A robot may not injure a human being, or, through inaction, allow a human being to come to harm.
- Third Law: A robot must protect its own existence as long as such protection does not conflict with the First or Second Law.
- Zeroth law: A robot may not injure humanity, or, through inaction, allow humanity to come to harm.

First Movie on Robots

- "Metropolis" from Fritz Lang released in 1926.
- The female robot "Maria" in the film is the first robot to be projected on a movie screen.



George Lucas Movie: STAR WARS

- Star Wars, 1977:, Introduces two robots: R2-D2 and C-3PO

Robot Definitions

- Robotics Institute of America (1975):An industrial robot is a reprogrammable, multifunctional manipulator designed to move materials, parts, tools, or specialized devices through variable programmed motions for the performance of a variety of tasks.

- Webster's Dictionary: A robot is an automatic apparatus or device that performs functions ordinarily ascribed to humans or operates with what appears to be almost human intelligence.

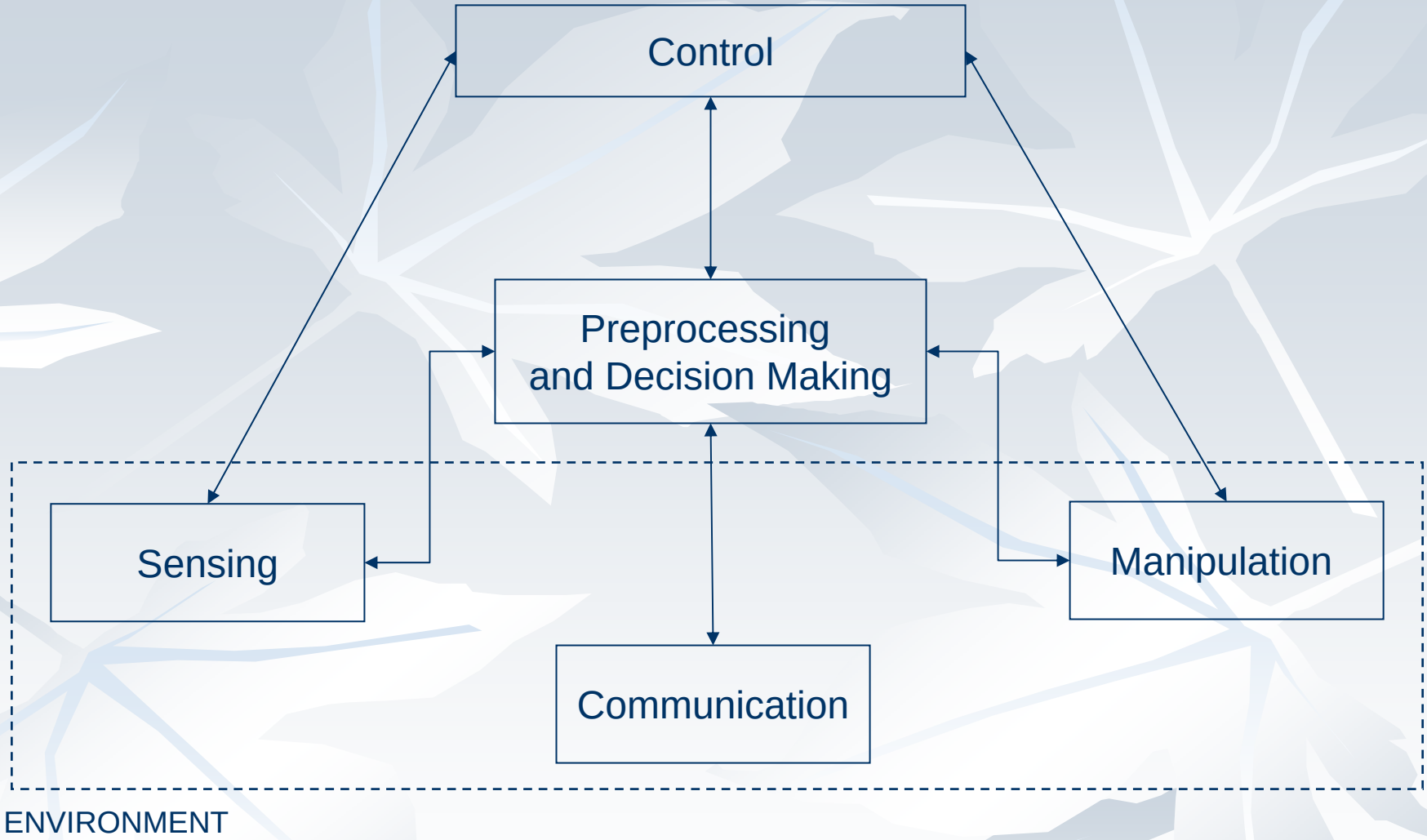
Robot Definitions

- ISO (1988): “An industrial robot is an automatic, servo-controlled, freely programmable, multipurpose manipulator, with several axes, for the handling of work pieces, tools or special devices. Variably programmed operations make possible the execution of a multiplicity of tasks”.

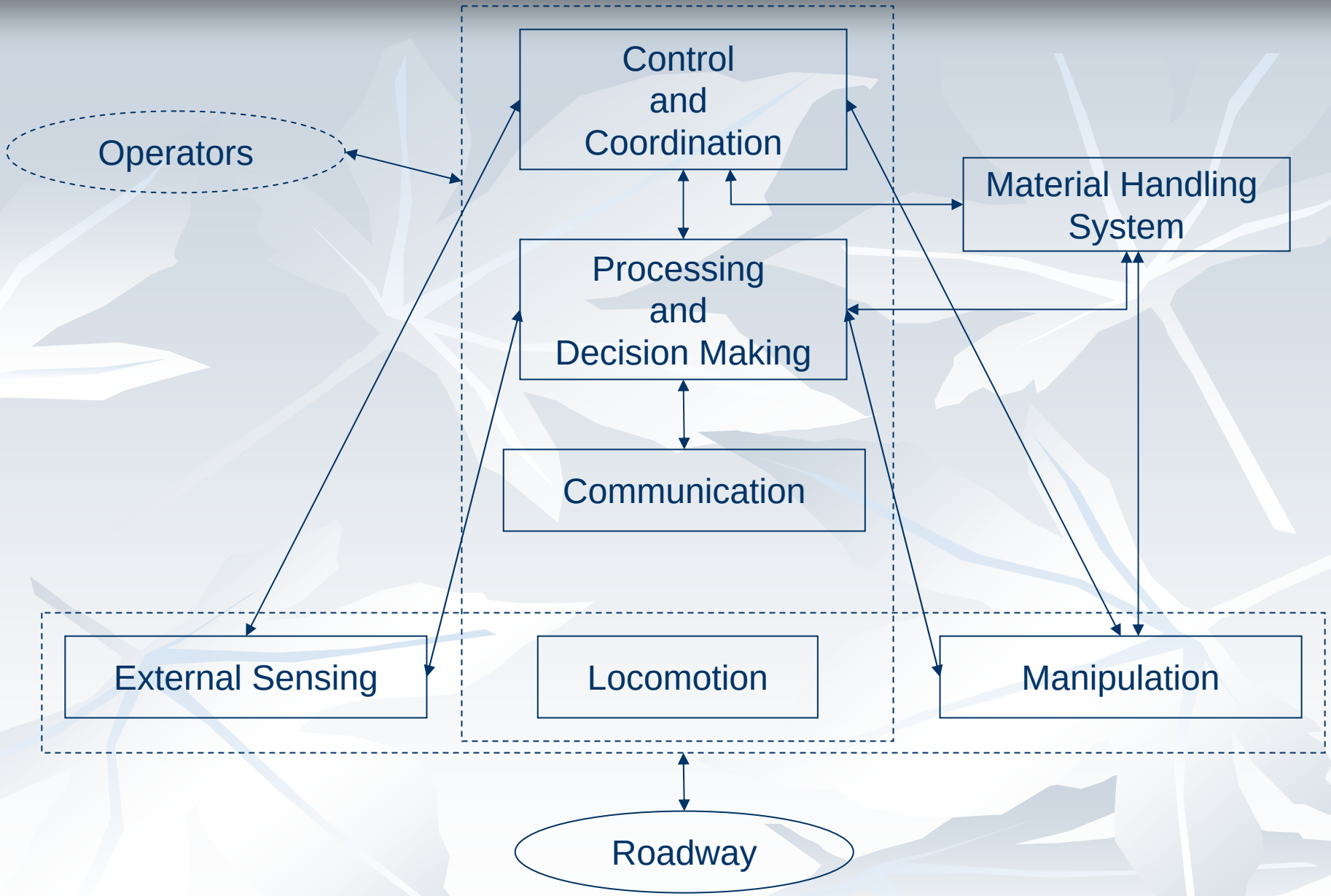
- IFToMM (1991): A robot is a “Mechanical system under automatic control that performs operations such as handling and locomotion”; and Manipulator as ”Device for gripping and controlled movements of objects”.

- IEEE Community (2000): “A robot is a machine constructed as an assemblage of joined links so that they can be articulated into desired positions by a programmable controller and precision actuators to perform a variety of tasks”.

Examples of Industrial Robots (Adept Technology)

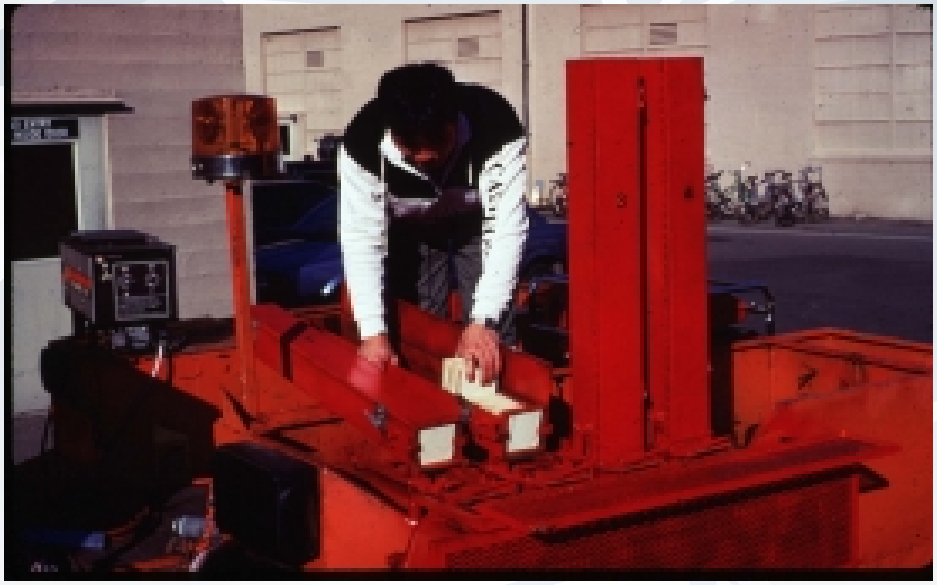


Functional Block Diagram of a Robotic System

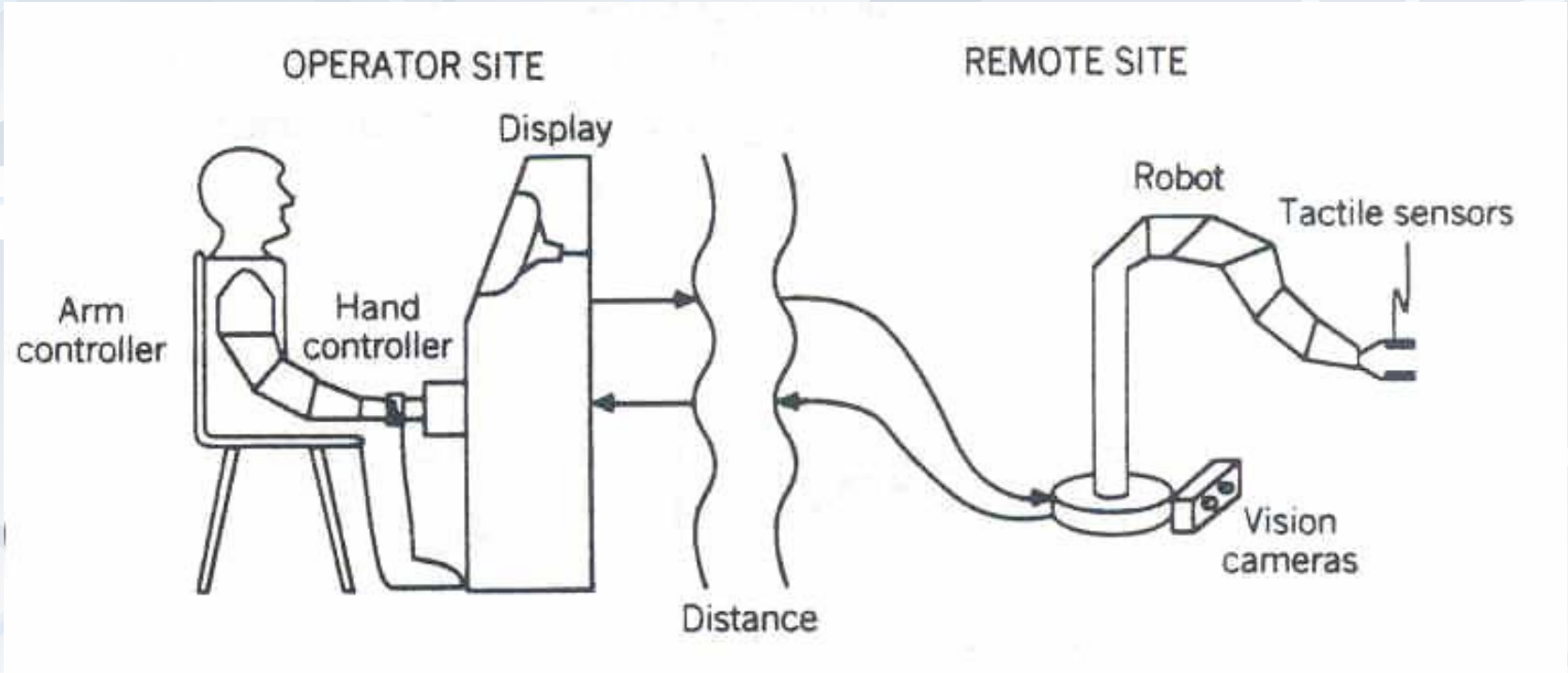


Functional Architecture of a Robotic System for Highway Maintenance Applications

First Highway Applications



Future Highway Applications



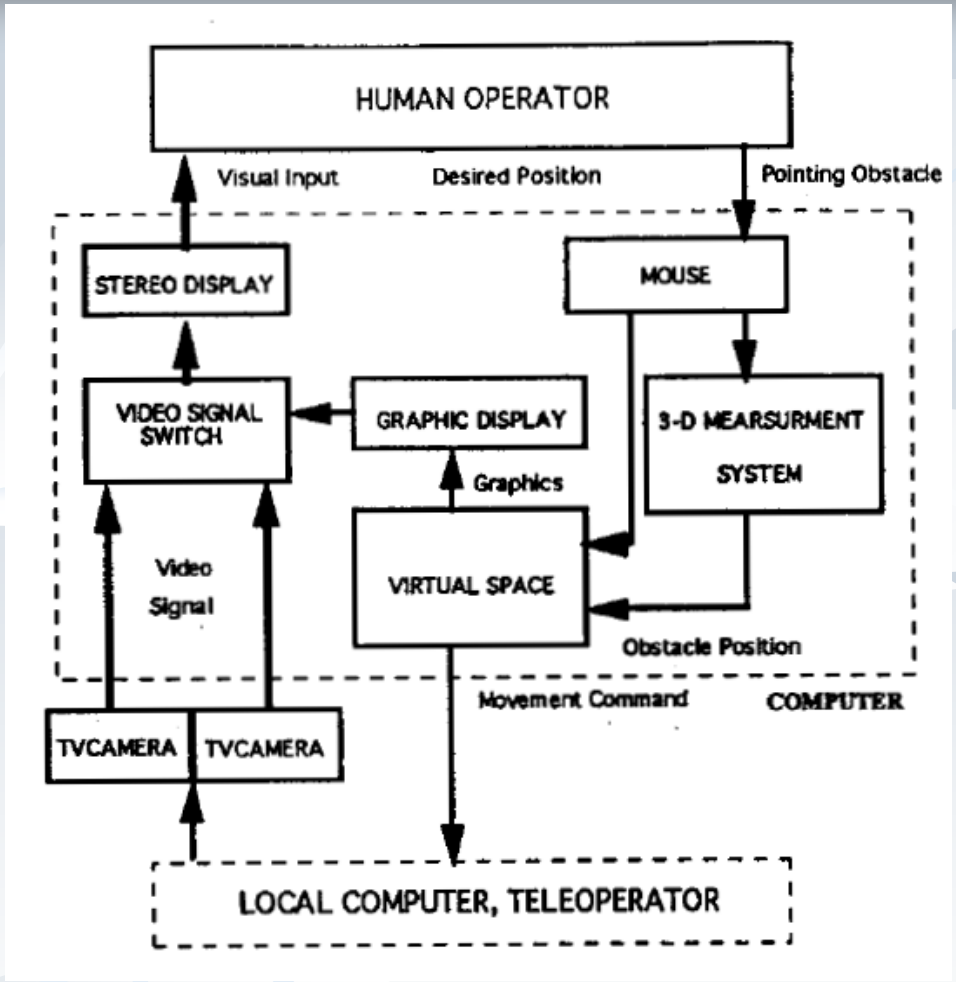
Tele-operations (Handling of Remote tasks)

Remote Roadway

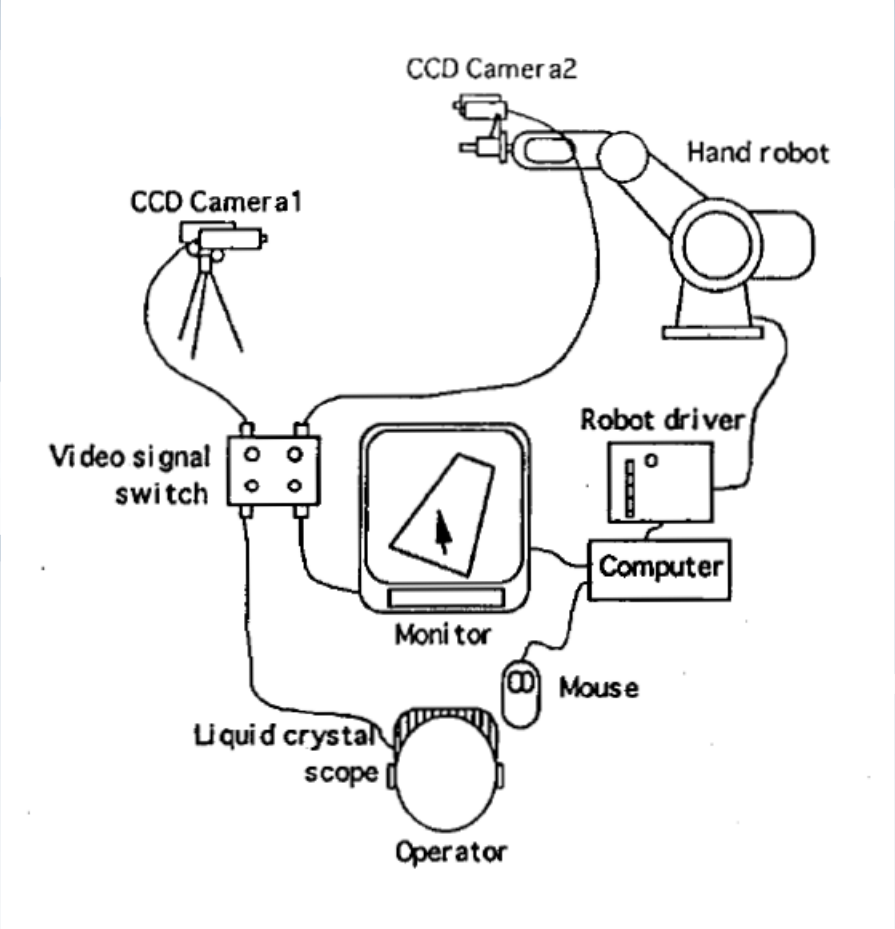
Operations from inside the truck

Future: Operations from office / TMC

Remote Drivers

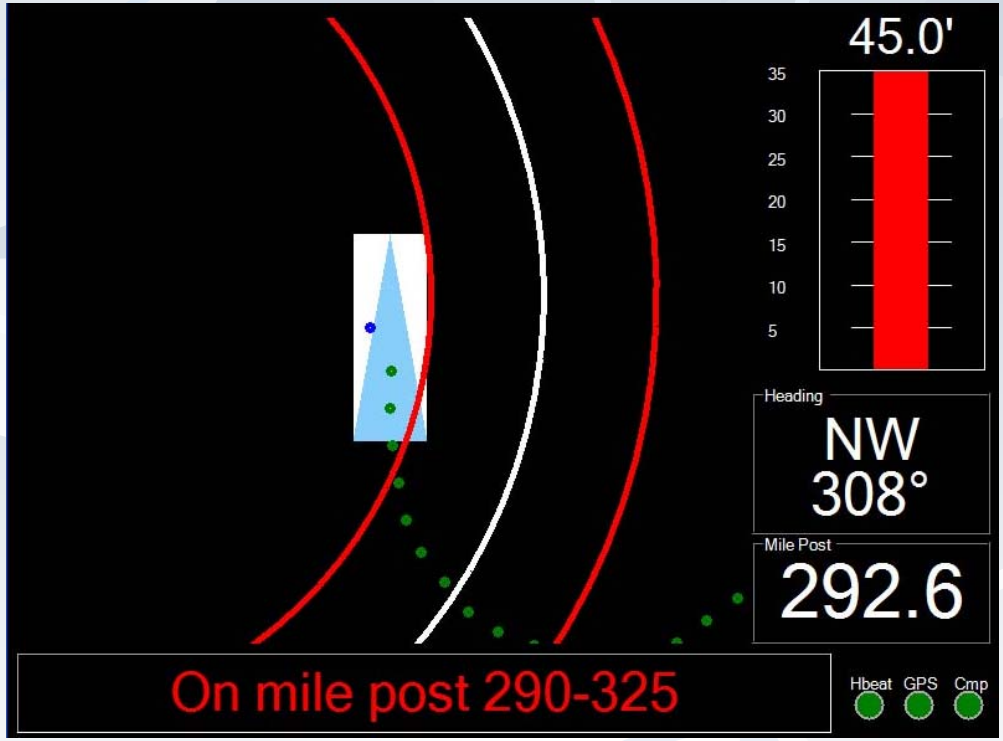


Tele-presence



Transparent Operations for the Operator

Transparent Roadway

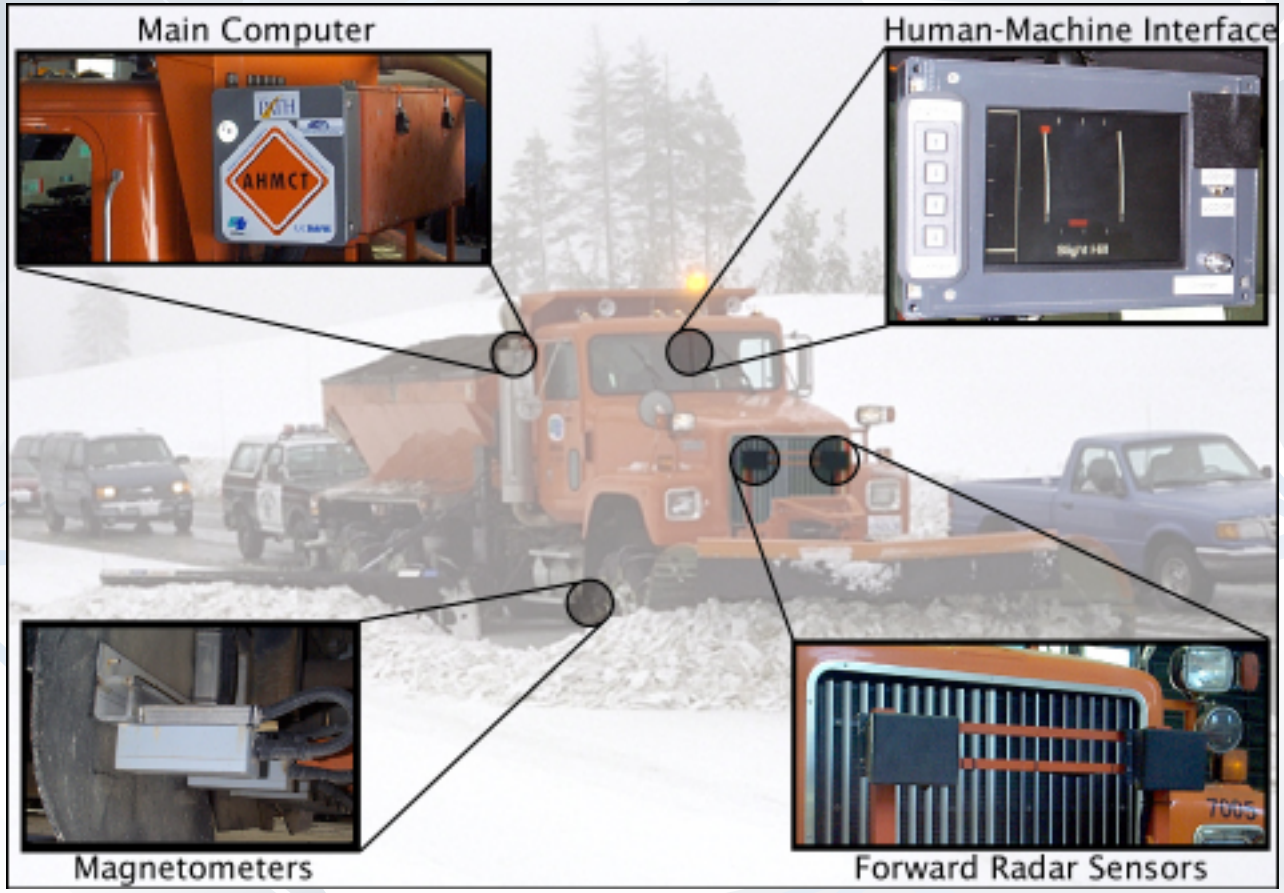


Driver Assistance for Snow Plowing Operations

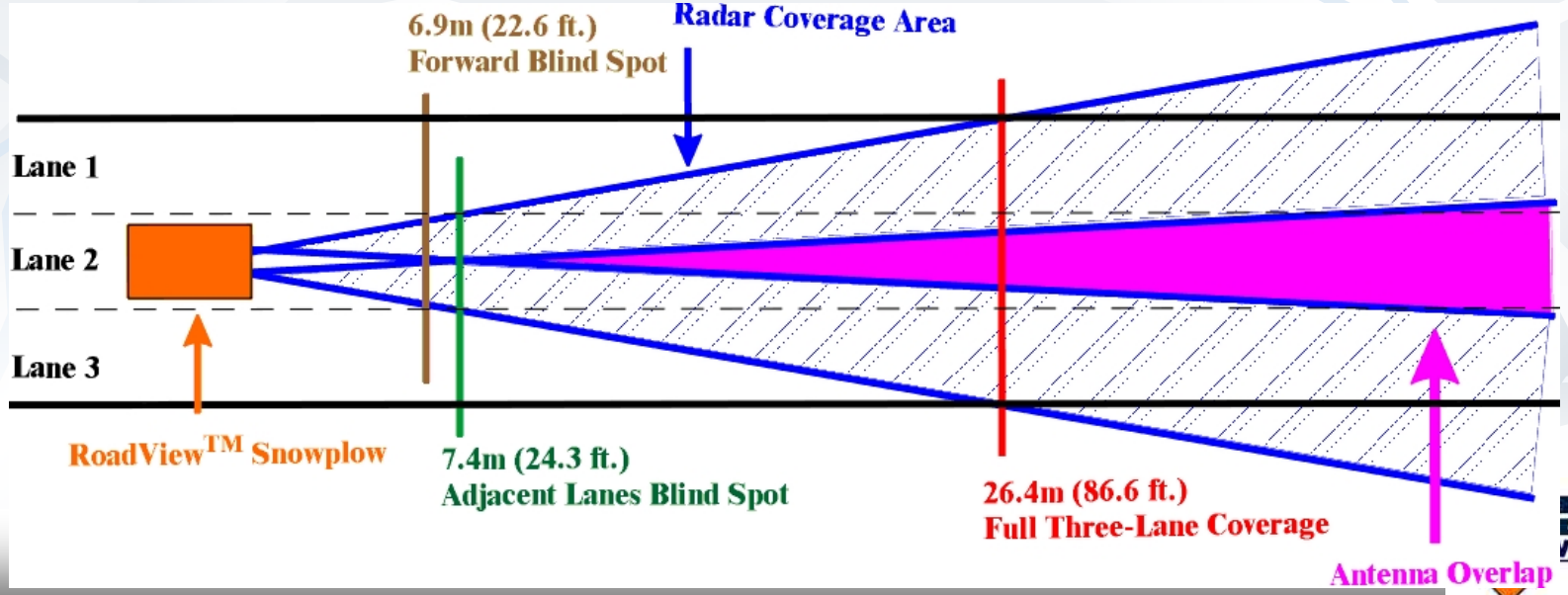
Automation

- Sensing (Conventional, GPS) and Actuation
- CAD & GIS
- Computer Aided Metrology
- Data Bases and Automatic Searching
- Web Browser and Searches (IT)

Conventional Sensing



Radar Based Collision Warning System



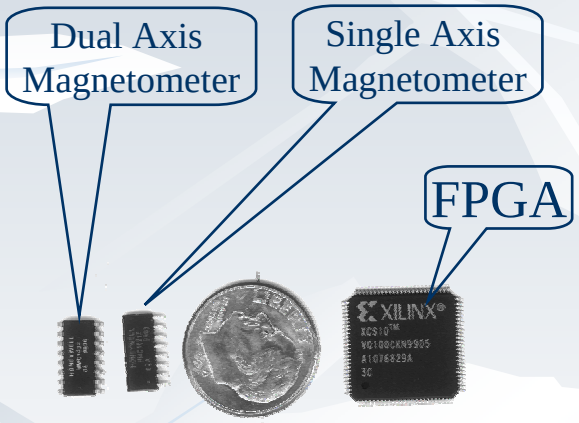
Driver Assist Components

Difficulties Encountered:

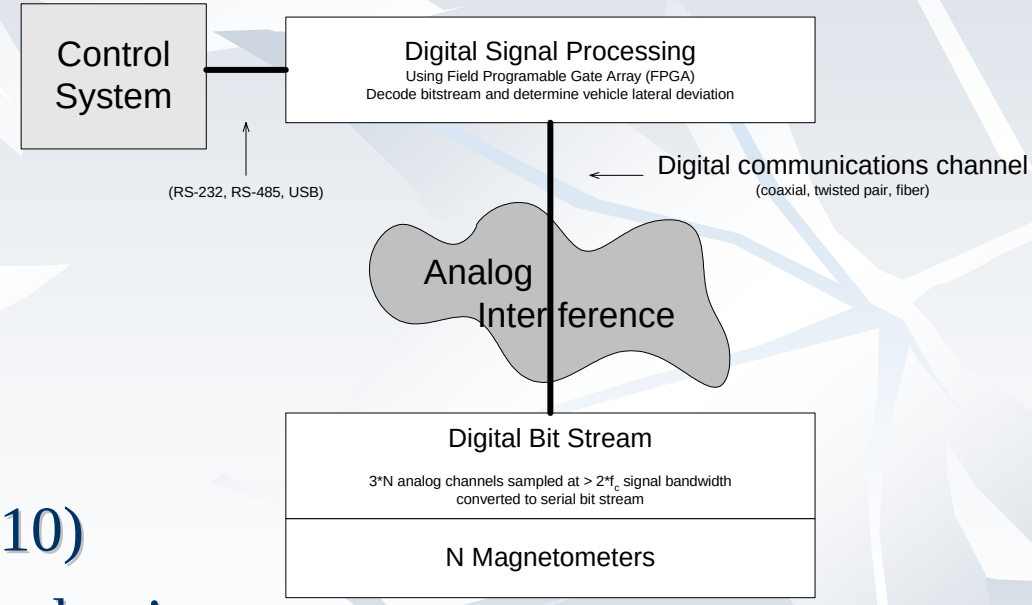
- Magnetic Sensing Components and Devices were not Robust, Rugged, and Easy to Install and Maintain on Vehicles

- Driving was difficult with HMI

New Magnet Sensing System for the Snow Plow

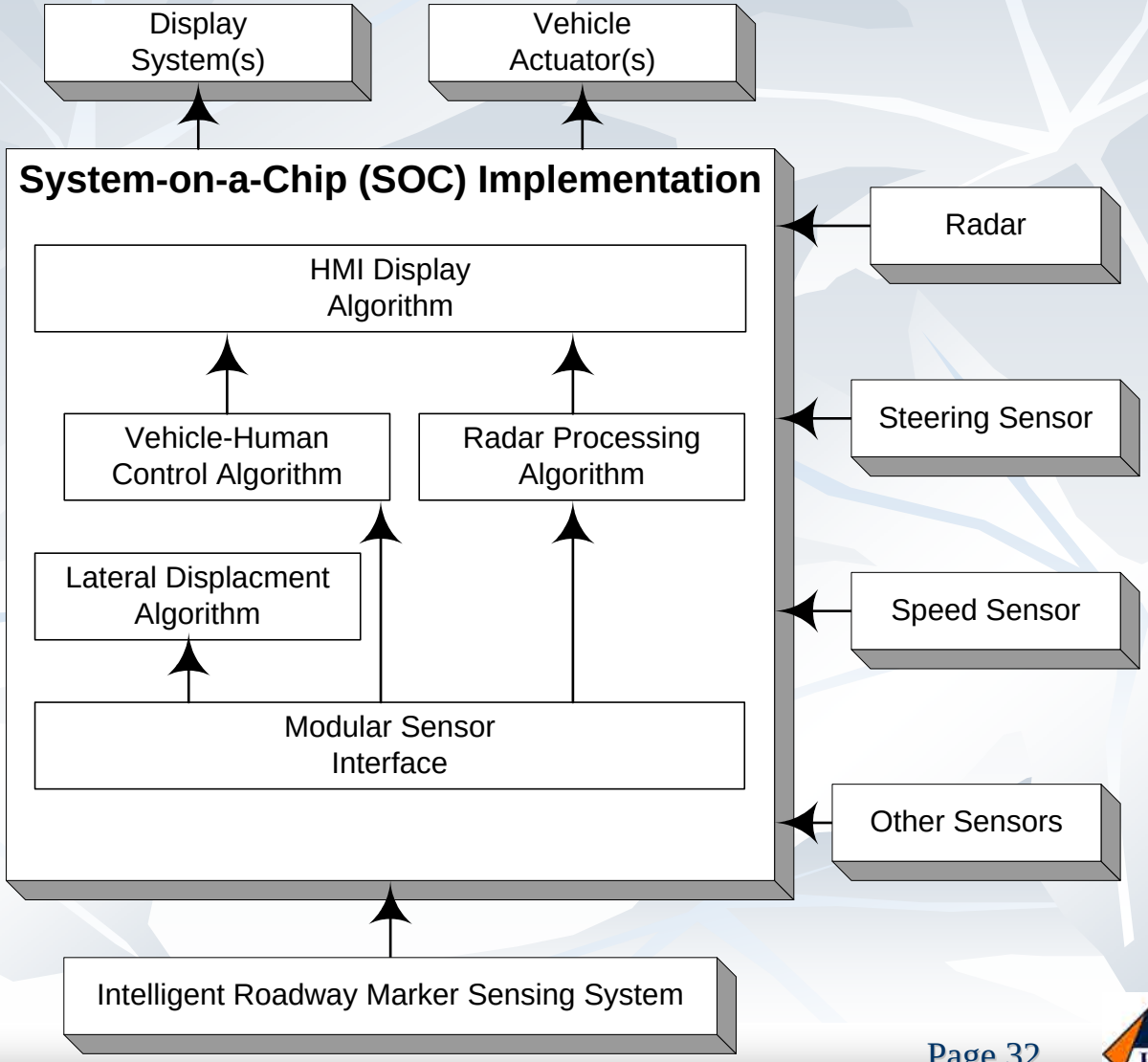


Next Generation Control Signal Acquisition System

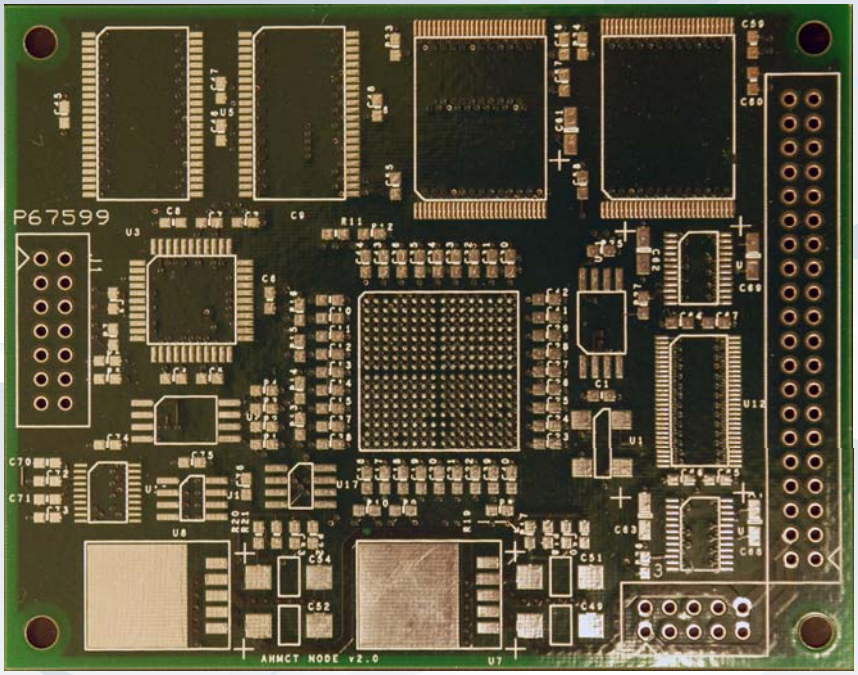


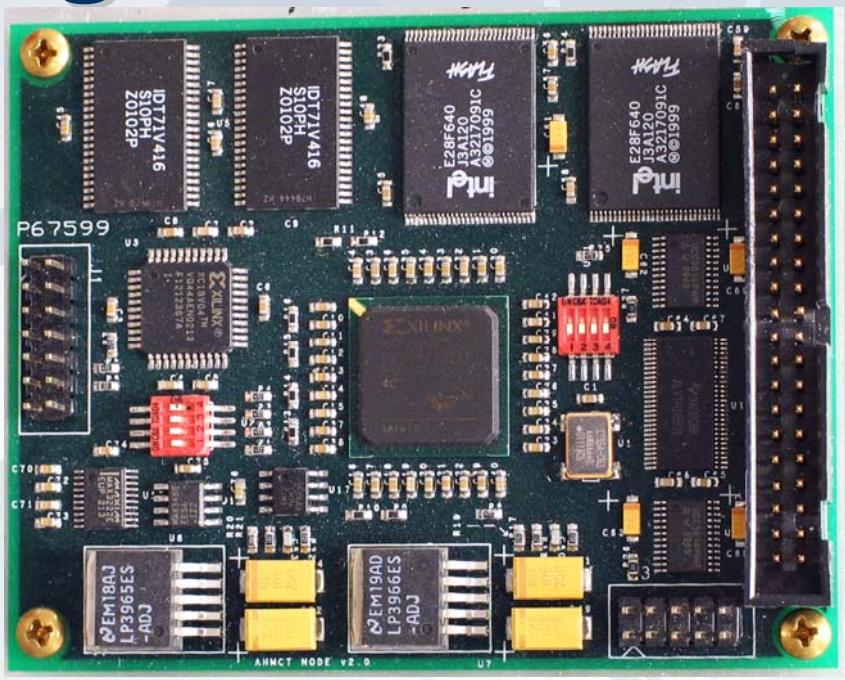
- Benefits
  - Lower Cost (approx. factor of 10)
  - Space & Wiring Reduction (approx. 50%-75%)
  - Robust and Noise Insensitive

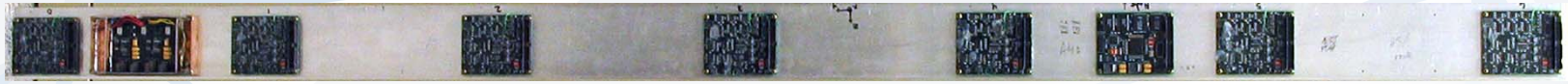
Physical architecture, including SoC implementation of functional blocks



Smart Magnetometer

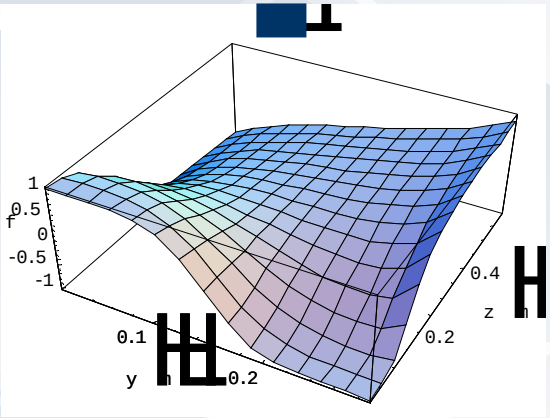






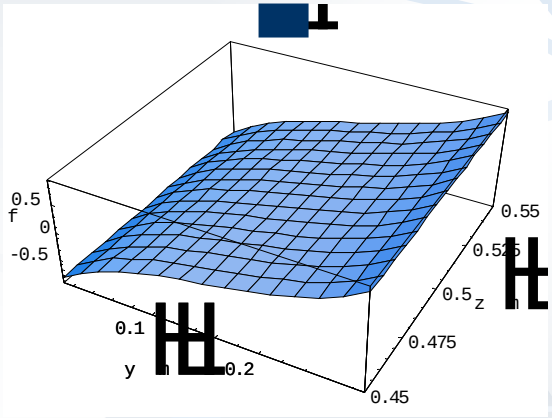
f() for discrete magnetic markers

For fixed $x_0 = 0$



Implies need to constrain the (x , z) domain

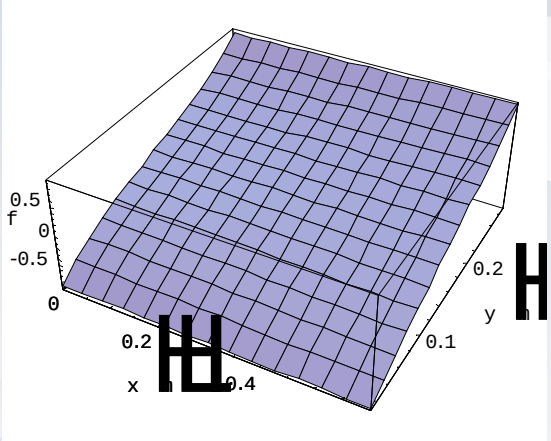
With restricted domain



$z \in \mathcal{D}$

Note: very little dependence on z, and strong dependence on y

f() for discrete magnetic markers

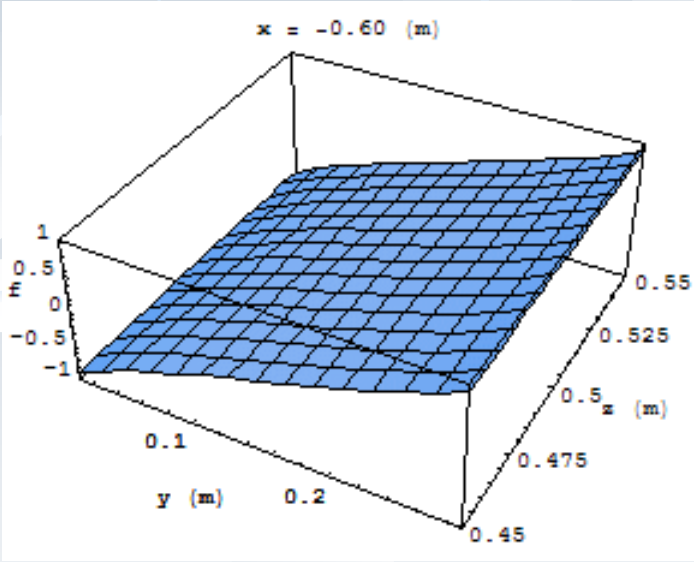


For fixed *z*

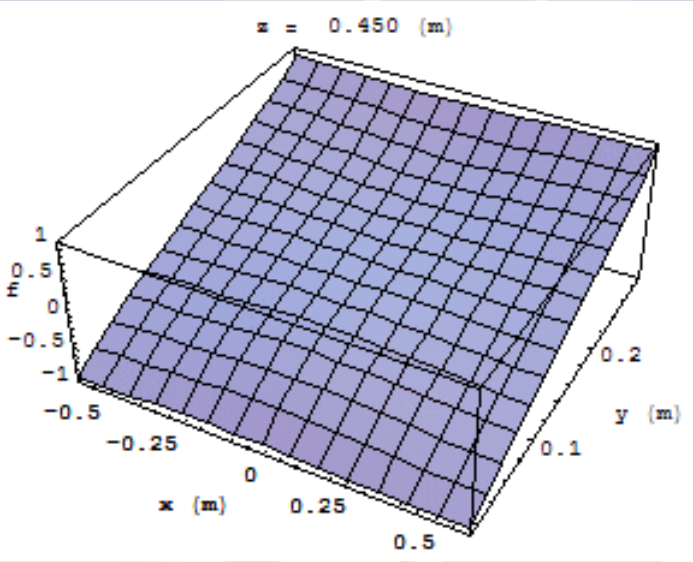
Note very little dependence on *x*,
and strong dependence on *y*

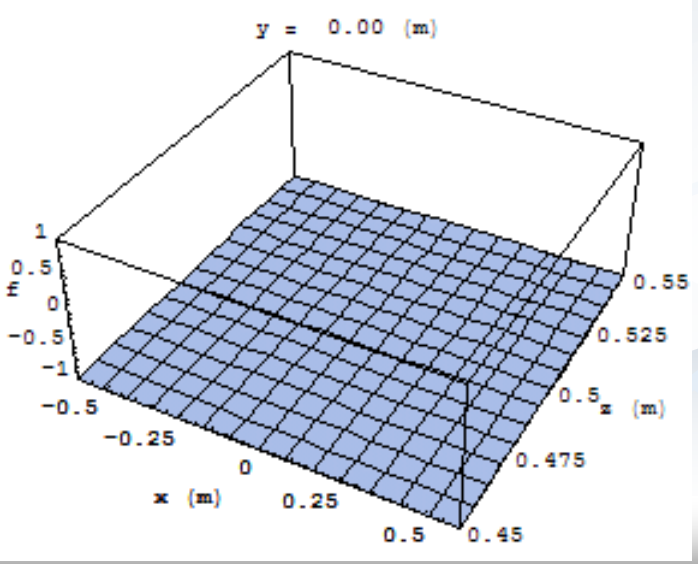
Discrete Magnet Surface Animations

Driving along road



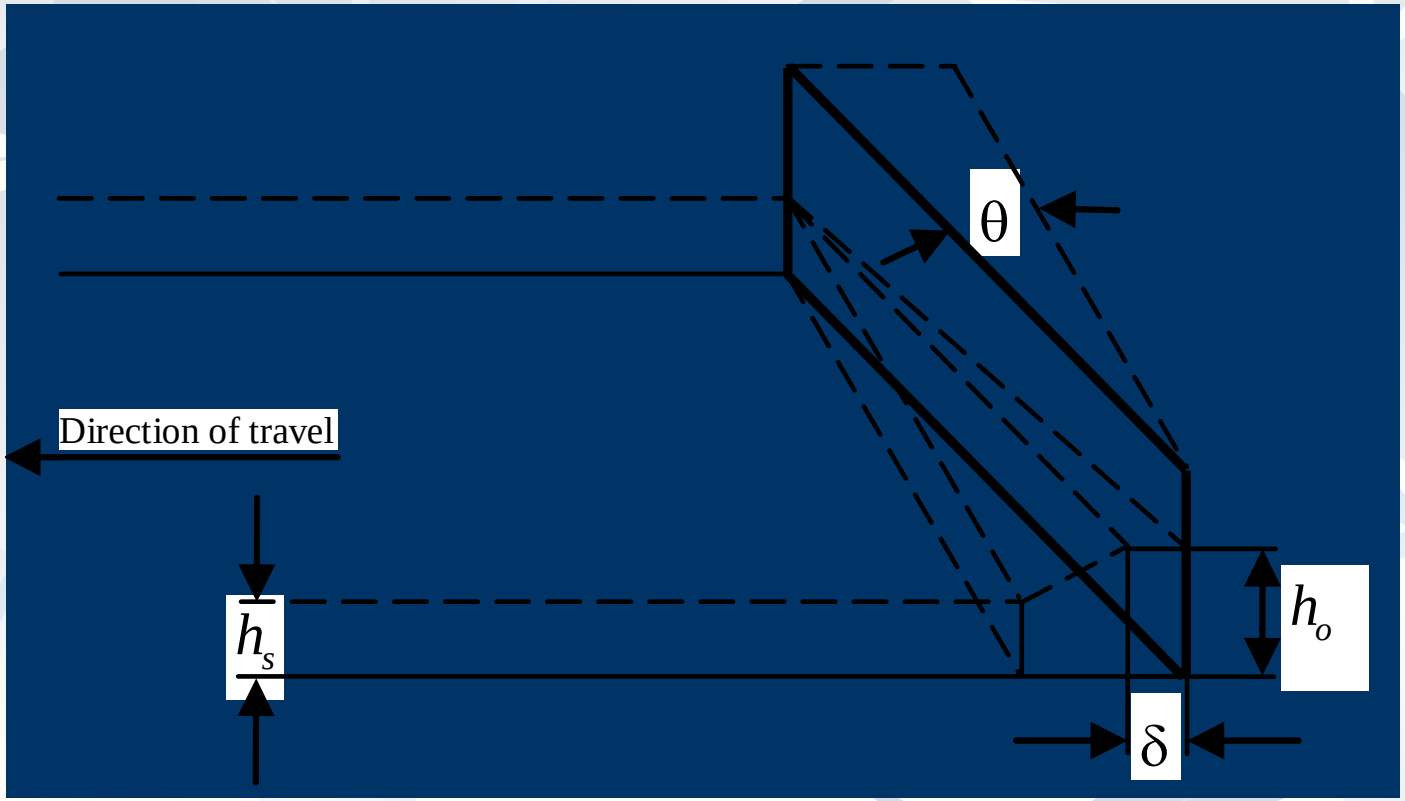
Vehicle bounce





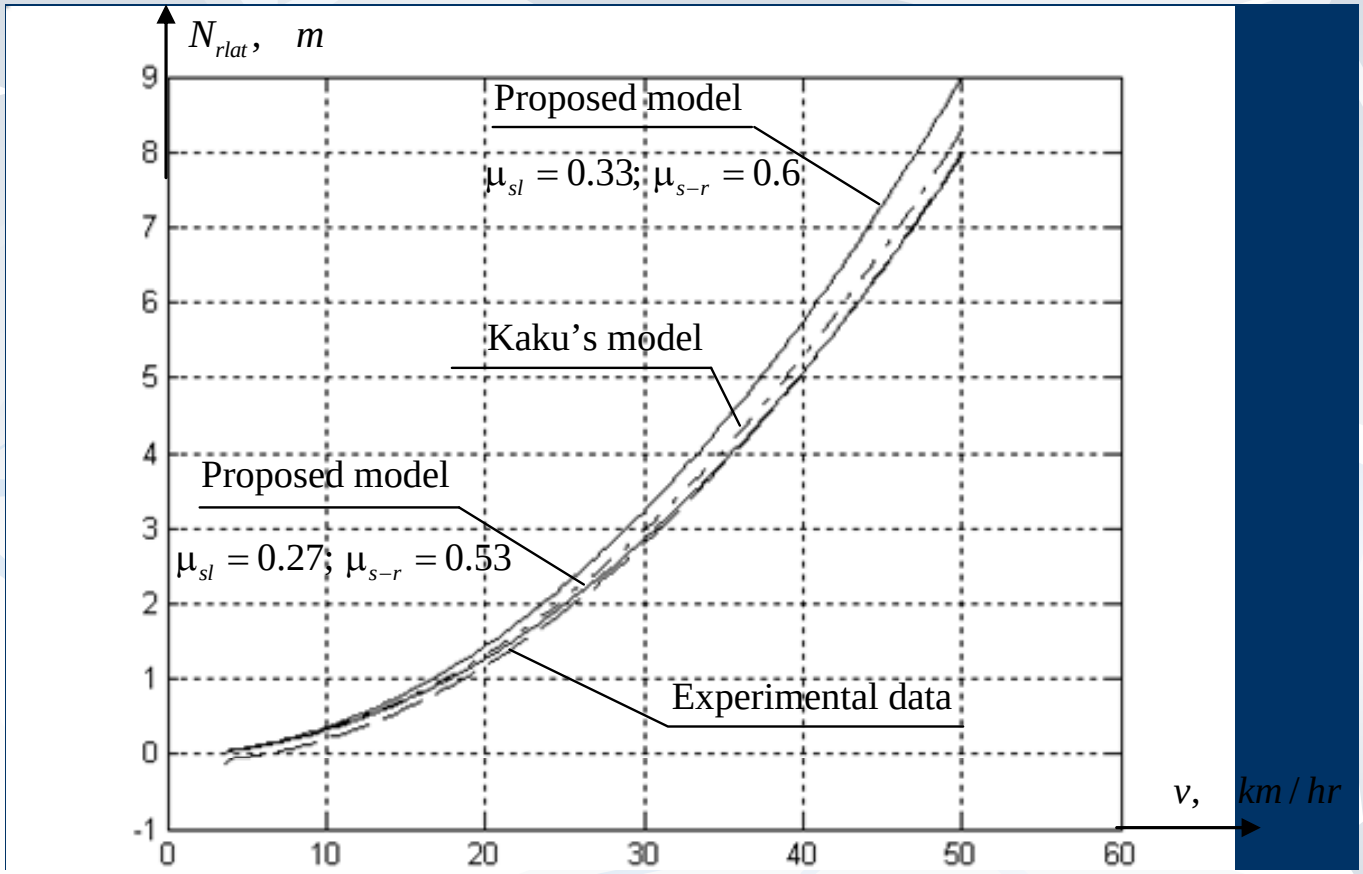
Lateral position,
i.e. slide across magnet

Snowplowing Resistance Model



Comparison of the Results For Lateral Forces

$$F_{lat} = F_{s-rfr}\cos(\theta) = \mu N_p \cos(\theta) = \mu\left(\rho_1 h_s v^2 \left(l\cos(\theta) + \delta\sin(\theta)\right) + \rho_a h_{pa} L v^2\right)\cos^2(\theta).$$



Computer Based Metrology and Reverse Engineering

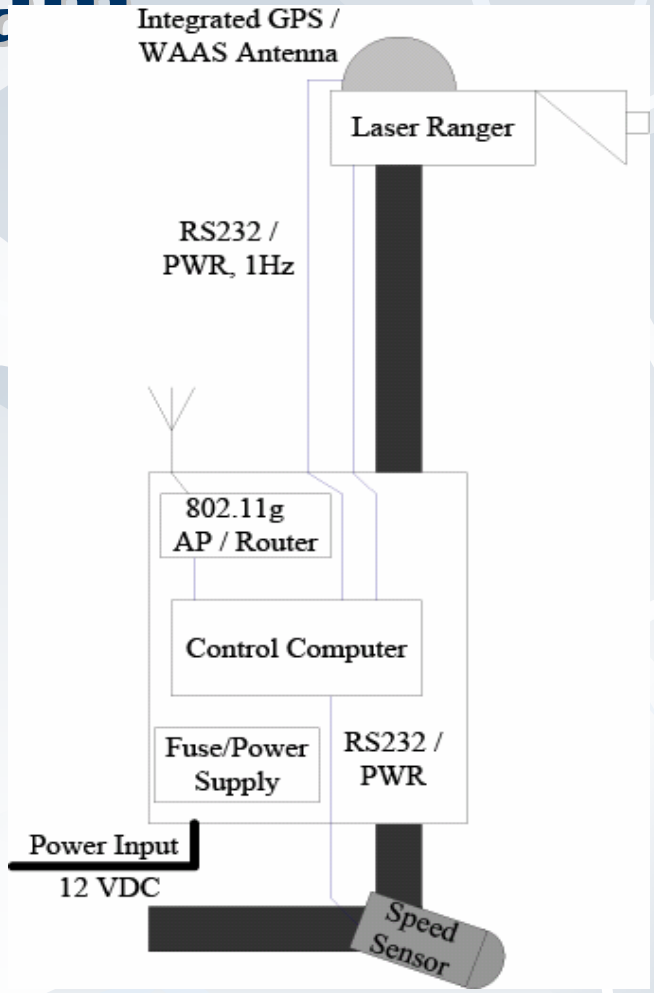
Applications in Laser Based Scanning and Measurements

AHMCT
UC DAVIS Caltrans

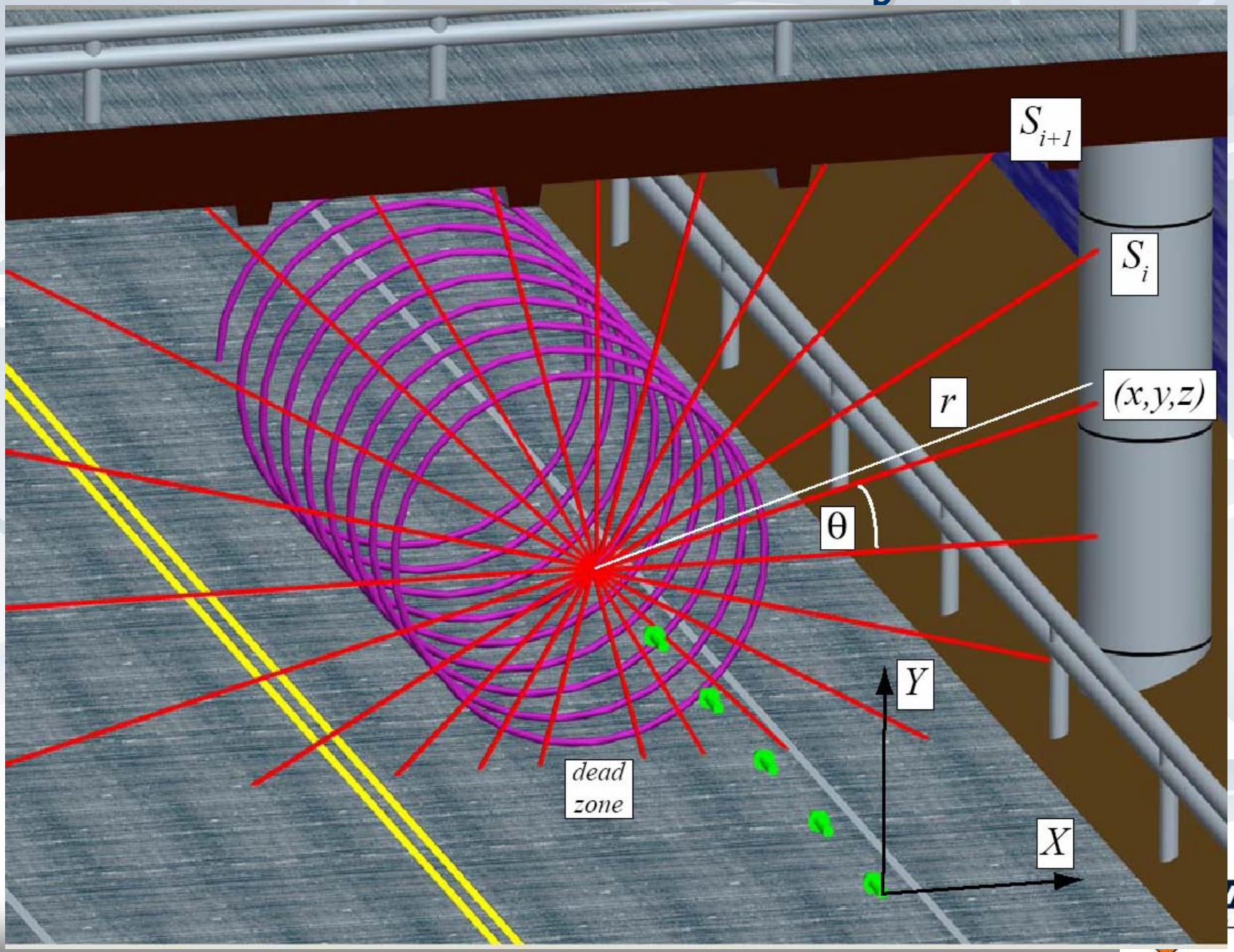
Bridge Height and Profile Measurements

- Profile data needed for permitting and homeland security
- Data collection can be dangerous, cause congestion
- Clearance data may be incomplete, inaccurate, difficult to maintain, difficult to access
- Several manual steps from data collection to database update

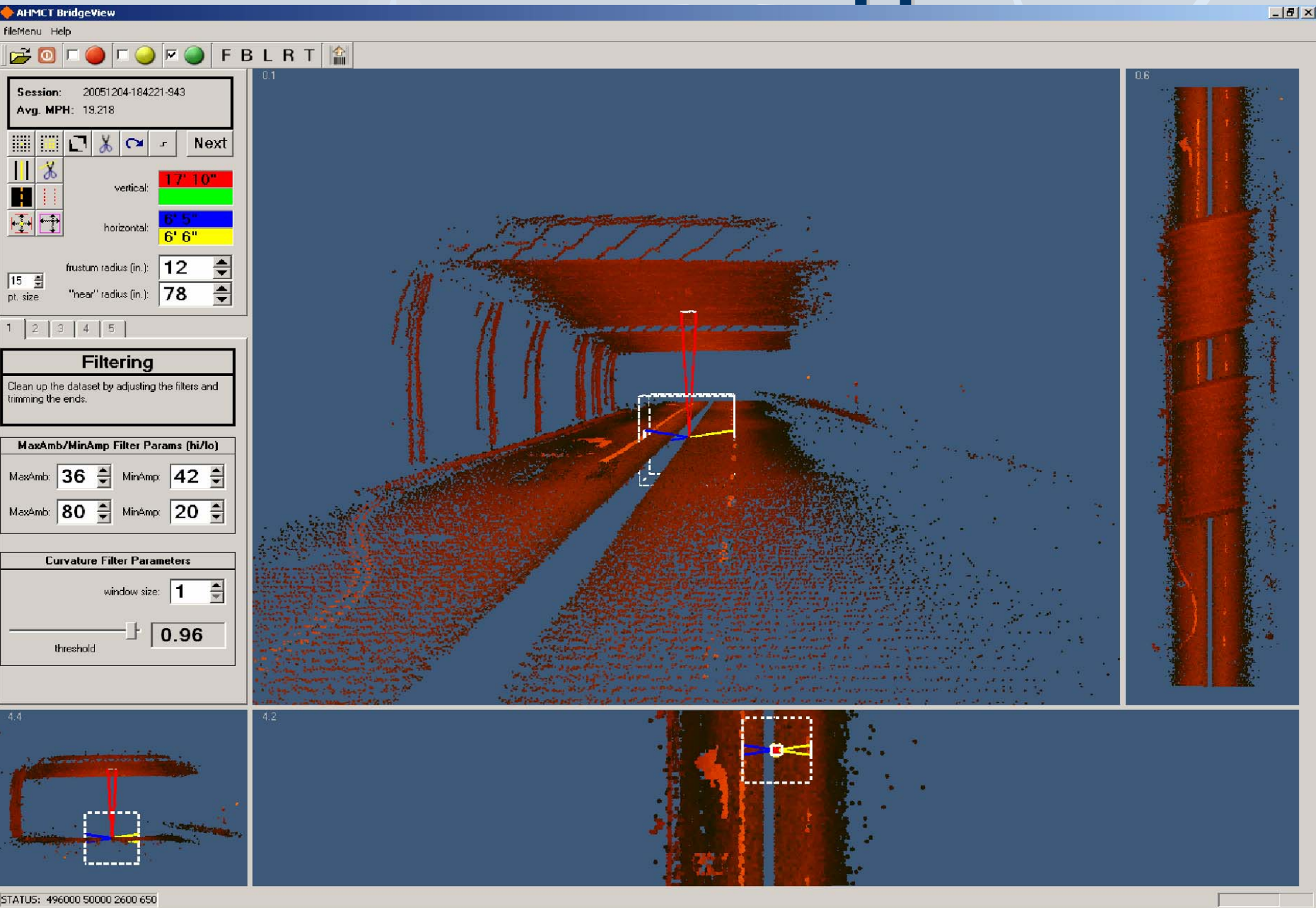
STRUCTVIEW and Block Diagram



Scan Geometry

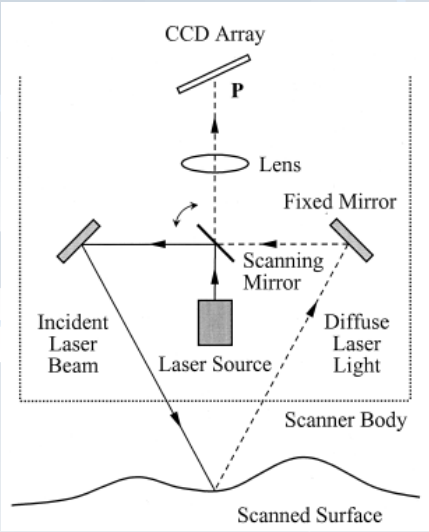


StructView User Application

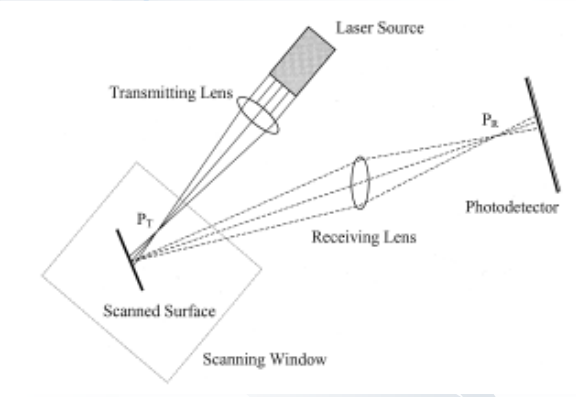


Benchmarking of Laser Scanners for Highway Applications

TECHNOLOGY

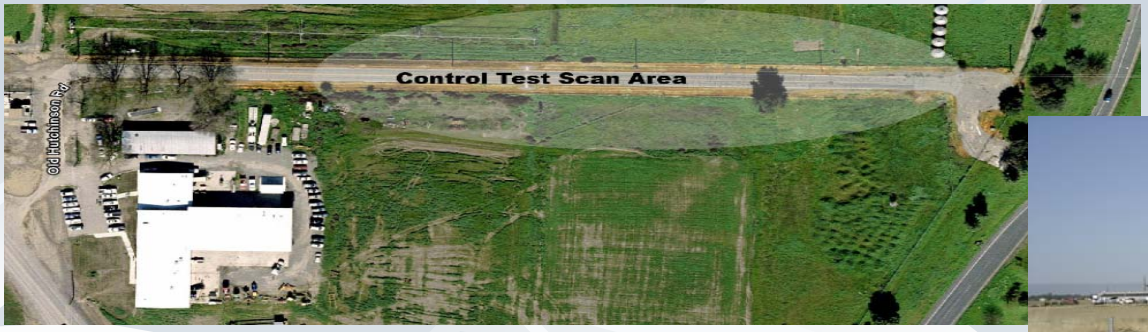


Working principle of laser scanner



Typical Laser Scanner Triangulation Geometry

EXPERIMENTATION/TESTS



Control Test Scan Area – Old Hutch Rd, 500m of asphalt road surface

Angular Accuracy/Sampling Interval

Point Acquisition & Surface Precision/ Noise

Angular Resolution

Range Accuracy

Incidence Coverage Angle

EXPERIMENTATION/TESTS (Contd.)

Pilot Test – 3D Scan of section of Highway 113 over Hutchison Rd

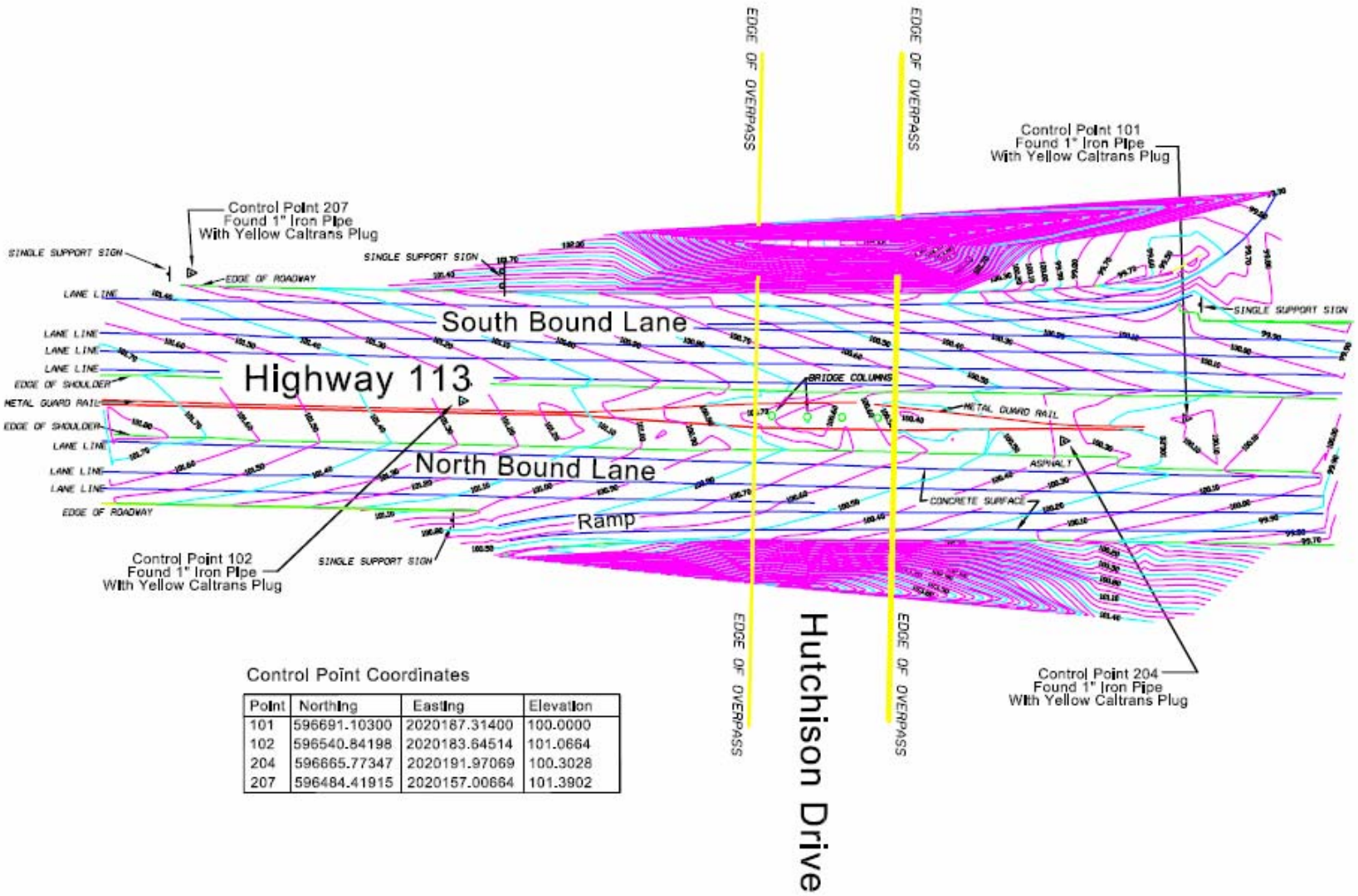
Pilot Test Scan Area – Bridge with clover-leaf ramps and specific geo-reference points at 25m, 50m and 100m on either side

The specifi[illegible] Pilot Study are:

•Colle[illegible] scan from each scan location

[illegible] Digital Terrain Model (DTM) [illegible] depicting the [illegible]

TYPICAL RESULTS

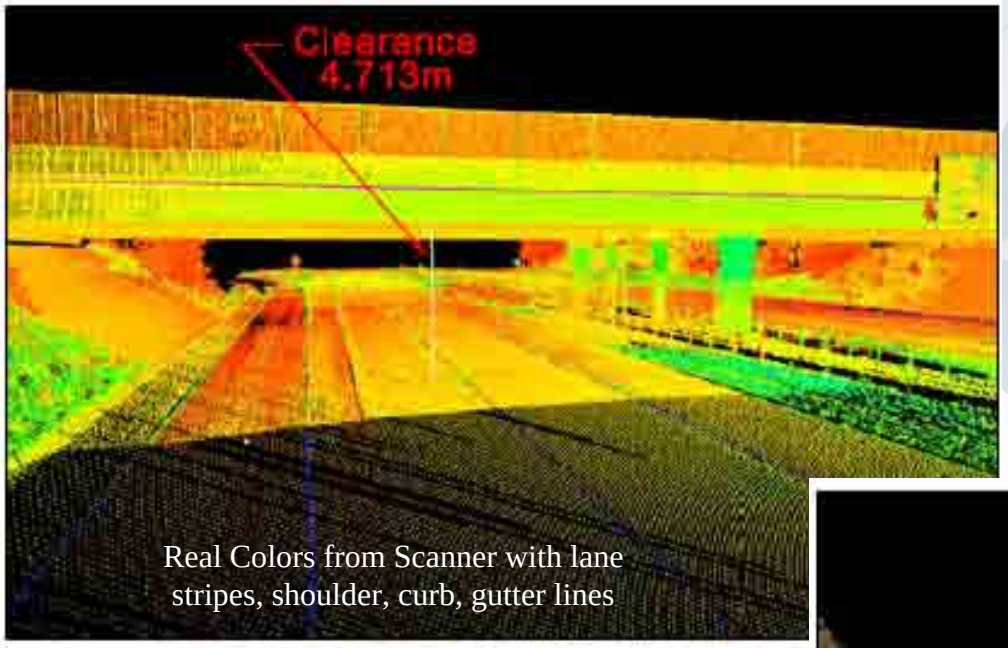


Control Point Coordinates

Point	Northing	Easting	Elevation
101	596691.10300	2020187.31400	100.0000
102	596540.84198	2020183.64514	101.0664
204	596665.77347	2020191.97069	100.3028
207	596484.41915	2020157.00664	101.3902

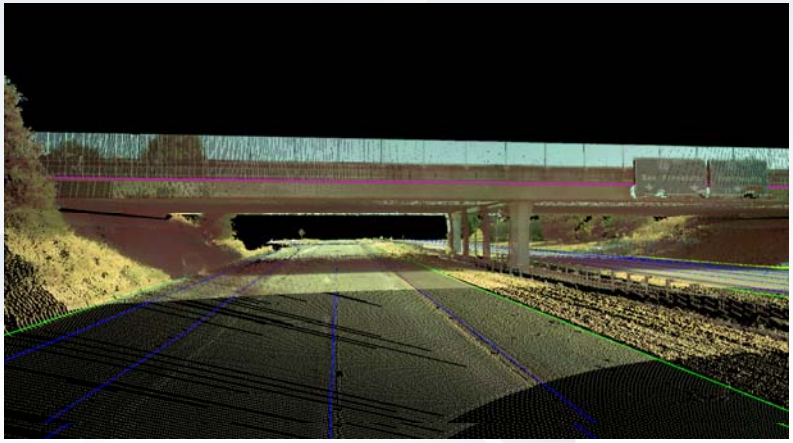
Map of State Highway 113 over Hutchison Drive

TYPICAL RESULTS (contd.)



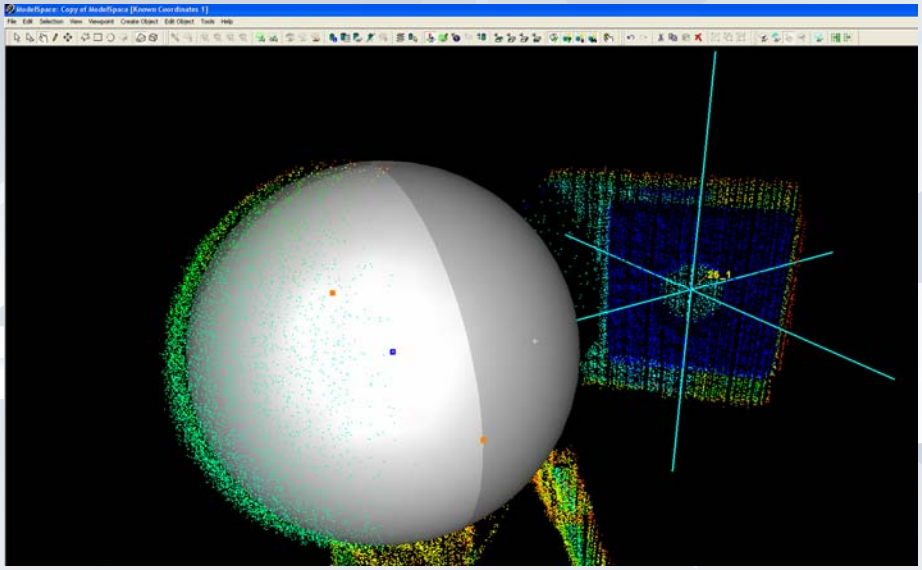
Real Colors from Scanner with lane stripes, shoulder, curb, gutter lines

South bound clearance – point cloud and colors from real image



Colors from Scanner with lane

TYPICAL RESULTS (contd.)



Point cloud of Angular Accuracy test with computed translational (left)

Angular Accuracy Test

To test angular accu[illegible] diameter spheres mounted on an [illegible] bracket alongside 3 in x 3 in square planar targets [illegible] millimeter-level translation using a lie[illegible] test is conducted for only two ra[illegible] and 75 m—and requires two scans. The [illegible] will be from the same scanner location, [illegible] the target location provided by the [illegible]

	N	E	Z	Measured Translation Distance	Net Distance Error
TS Measurement_Leica Target	20025.38039	10003.82263	101.30241		
25_1 sphere center	20025.284	10003.923	101.281		
25_1 sphere leica target_postn1	20025.379	10003.823	101.298		**0.004638653**
25_1 sphere leica target_postn2	20025.383	10003.827	101.299	**0.006126753**	0.000910
25_1 sphere leica target_postn3	20025.388	10003.831	101.297	**0.012539422**	0.001312

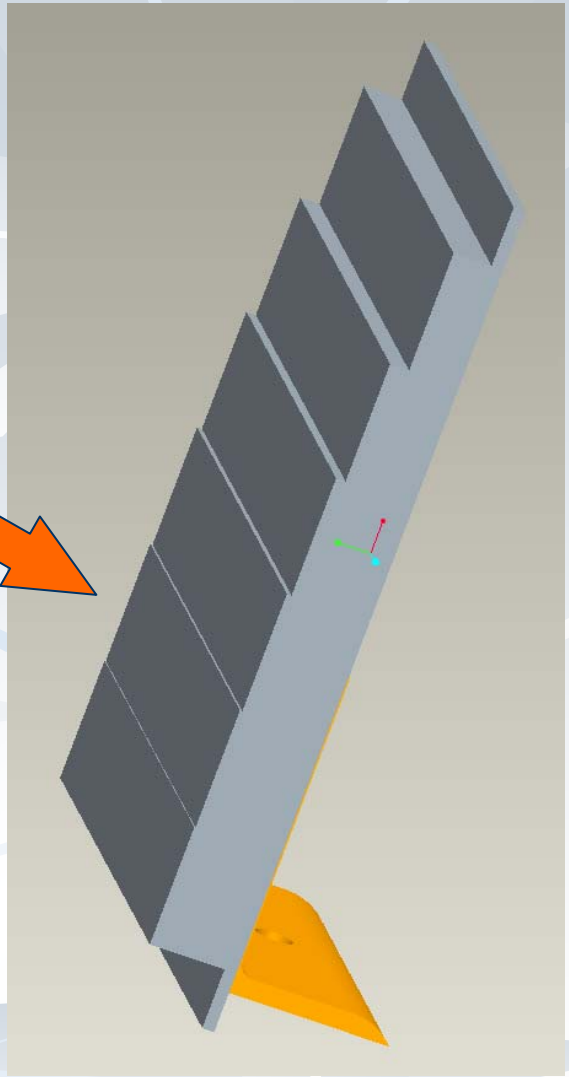
	N	E	Z	Measured Translation Distance	Net Distance Error
TS Measurement_Leica Target	19924.61435	9989.71350	101.26935		
75_1 sphere center	19924.573	9989.688	101.267		
75_1 sphere leica target_postn1	19924.615	9989.715	101.258		0.011467127
75_1 sphere leica target_postn2	19924.621	9989.719	101.259	0.008629745	0.002629745
75_1 sphere leica target_postn3	19924.629	9989.72	101.258	0.016027242	0.004027242

TYPICAL RESULTS (contd.)

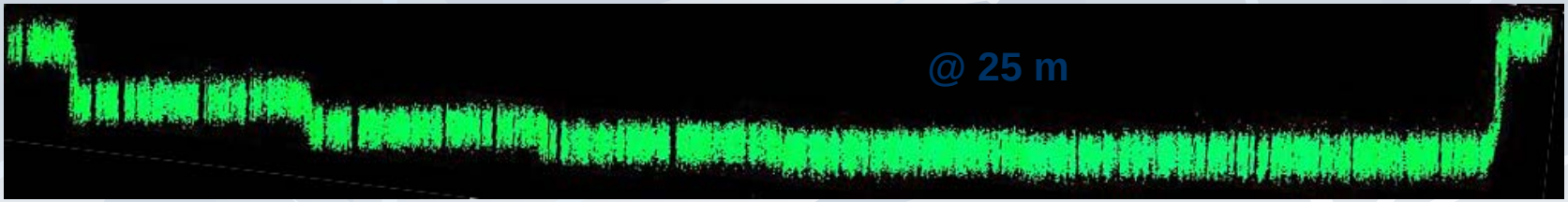
Surface Precision and Noise Acquisition Test

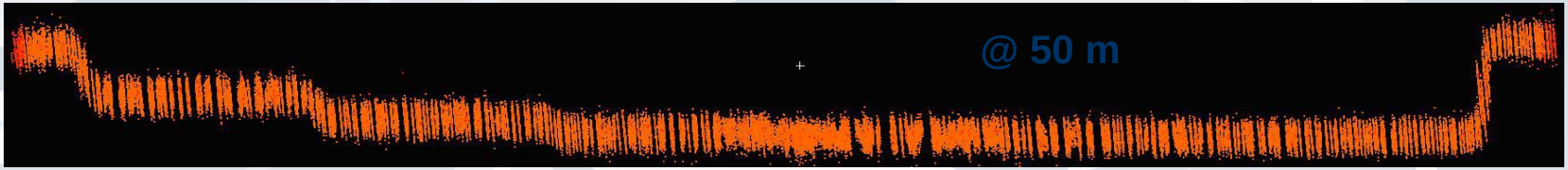
The fixture is a stair-type pattern on an 18 in x 12 in x 1.5 in thick precisely-machined aluminum block with the step-height varying from 0.02 in to ~ 5/8 in. One of these targets will be placed at each of the following ranges: 25 m, 50 m, 75 m and 100 m.

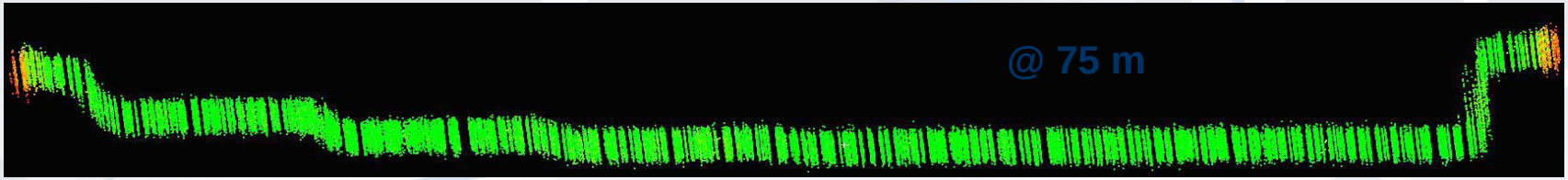
Line of sight of 3D Laser Scanner – For edge effects

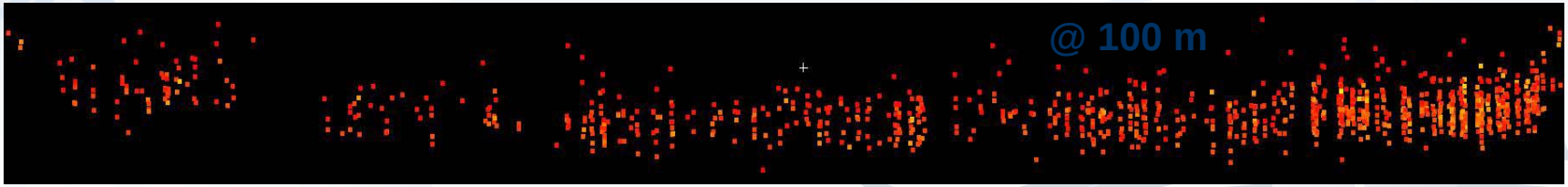


TYPICAL RESULTS (contd.)









TYPICAL RESULTS (contd.)

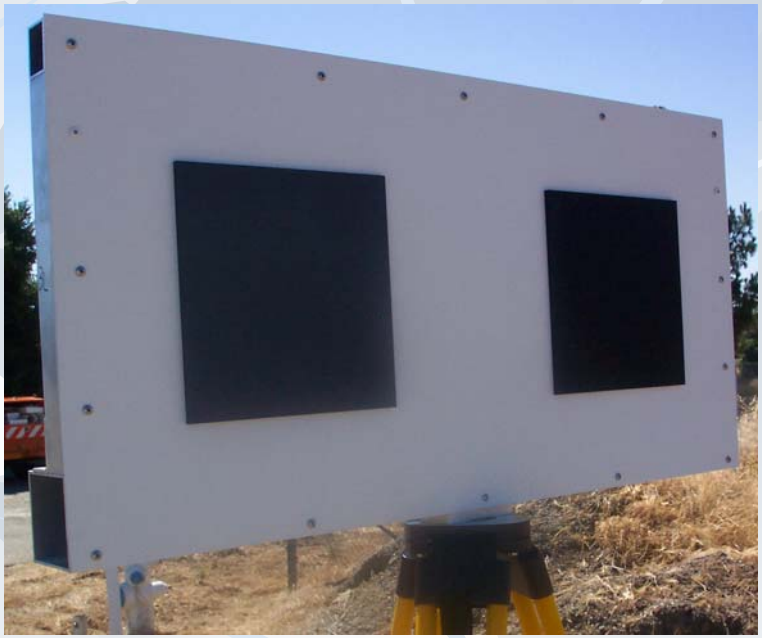
	Leica (m)	Trimble (m)	Optech (m)
White (25m)	0.005	0.006	0.007
Black (25m)	0.011	0.007	0.008
Grey (25m)	0.009	0.011	0.012
White (50m)	0.006	0.007	0.007
Black (50m)	0.015	0.009	0.011
Grey (50m)	0.011	0.012	0.013
White (75m)	0.008	0.008	0.009
Black (75m)	0.017	0.011	0.012
Grey (75m)	0.012	0.017	0.014
White (100m)	0.011	[illegible]	0.011
Black (100m)	0.021	[illegible]	0.016
Grey (100m)	0.019		0.021

Measured noise of Laser Point Cloud Data in meters

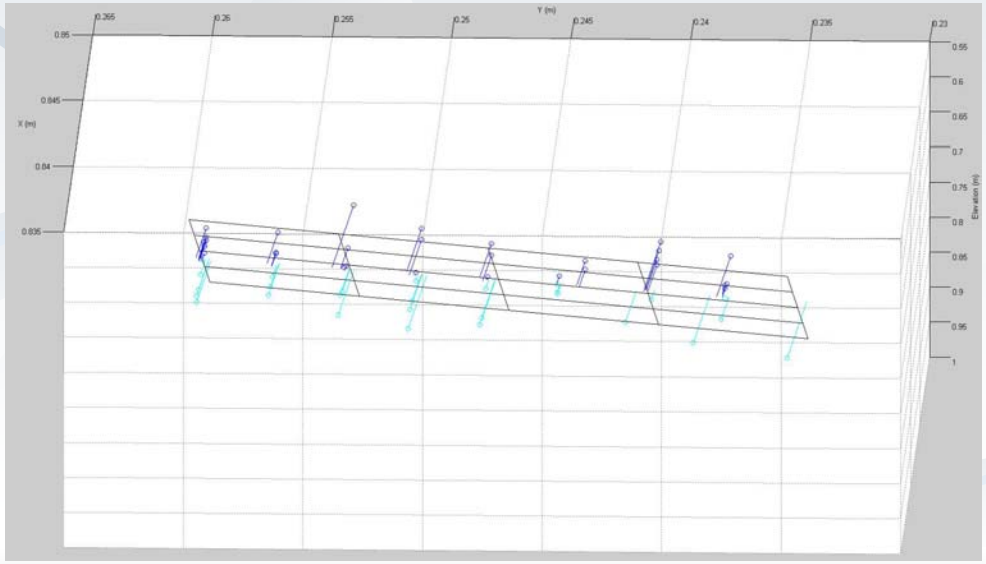
TYPICAL RESULTS (contd.)

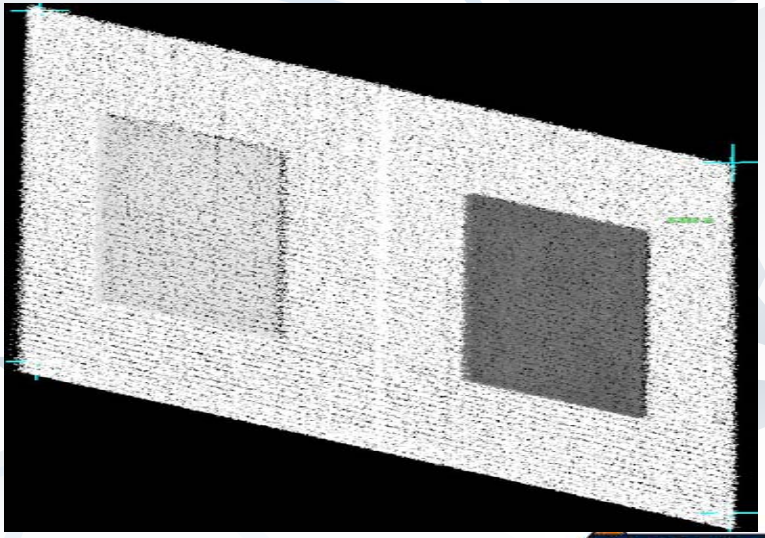
Range Accuracy Test

The test component is two 10 in x 10 in anodized flat aluminum plates with gray dull finish (reflectivity ~ 40%) and black dull finish (reflectivity ~8%) respectively, mounted on a 40 in x 20 in aluminum plate. Test ranges are 25 m, 50 m, 75 m and 100 m.



Range Errors plotted with interpolated surface and laser point cloud

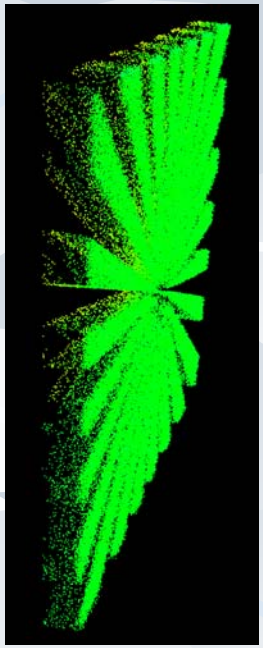


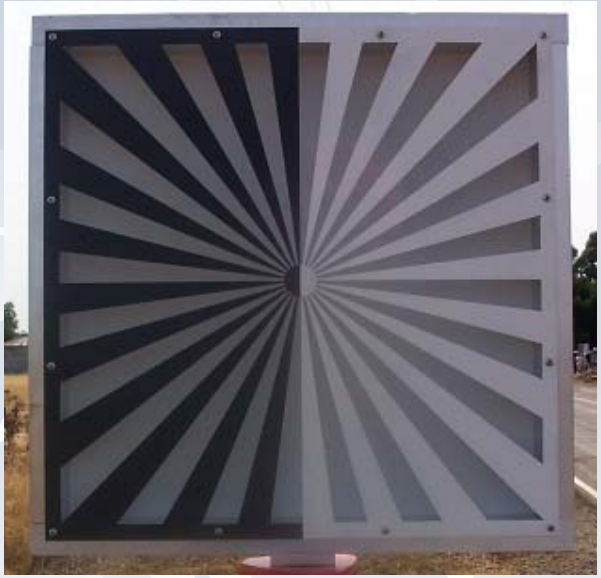


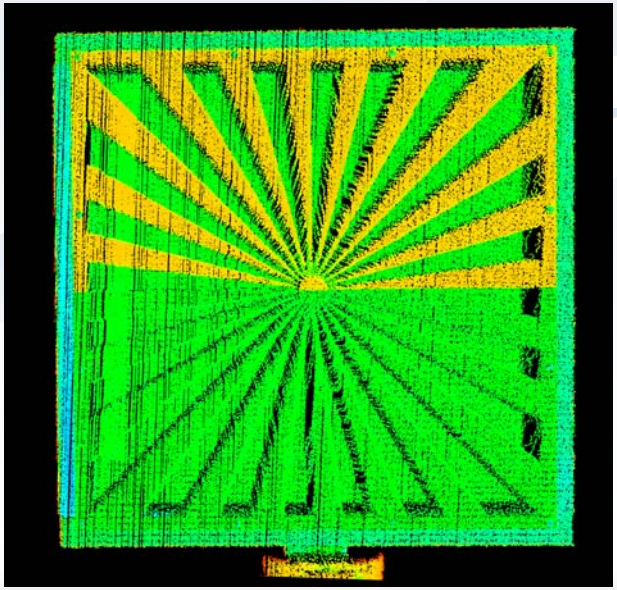
TYPICAL RESULTS (contd.)

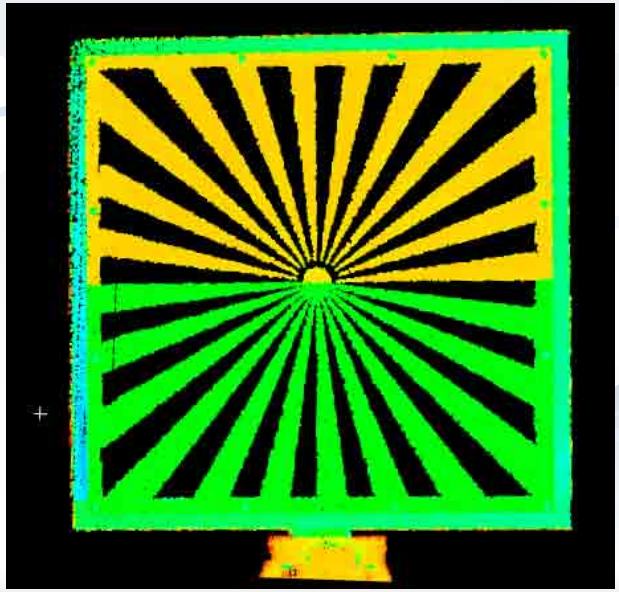
Angular Resolution Test

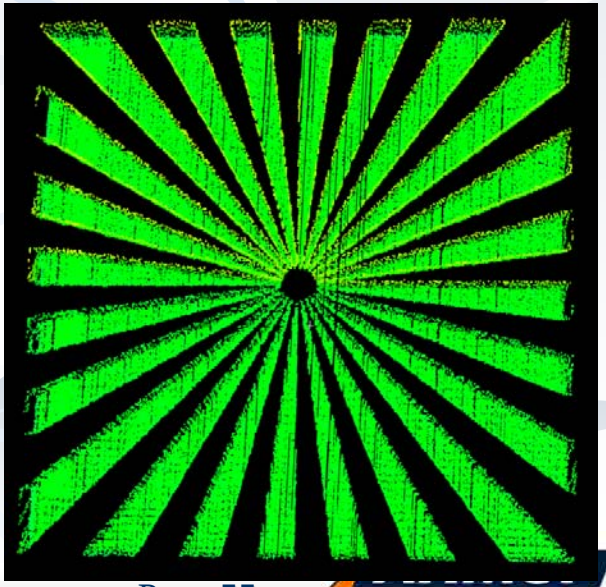
To test the ability of a scanner to resolve small objects, special target boxes are to be scanned at four ranges: 25 m, 50 m, 75 m and 100 m. These 24 in x 24 in boxes have a front panel containing tapered slots decreasing from about 2.5 in wide at the periphery to about 0.1 in at the center.



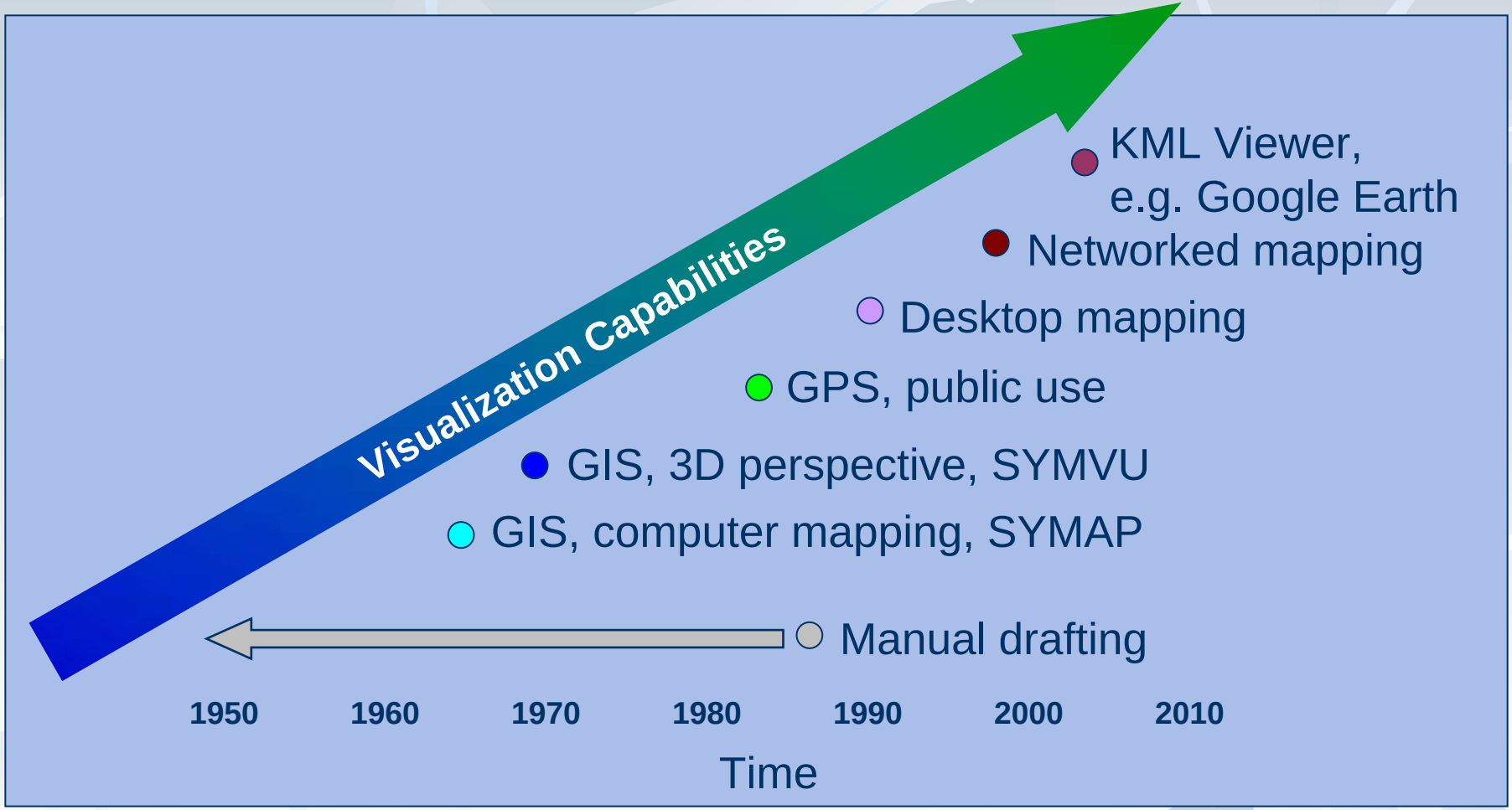








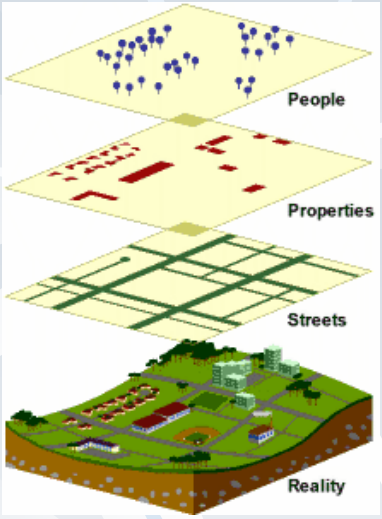
CAD/GIS, GPS, Visualization



Visualization has been moving towards a client that is:
3D + networked + collaborative + integrated

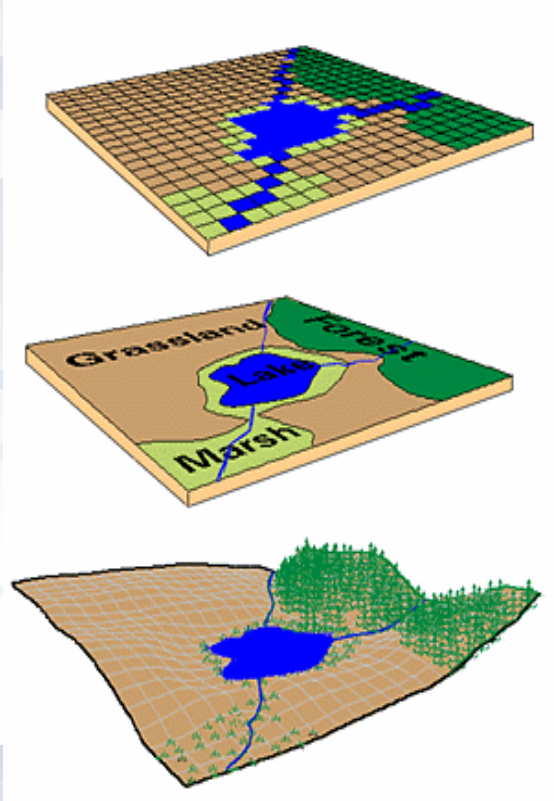
Geographic Information System (GIS)

- Consists of Spatial and Non-spatial Data
  - Spatial data refers to geographic areas or features. Features occupies a location.
  - Non-spatial data has no specific location in space, but have a geographic component and be linked to a geographic location.
- Themes
  - Themes link features with their attributes
  - Themes are linked by geography
- Collections of themes form a GIS database



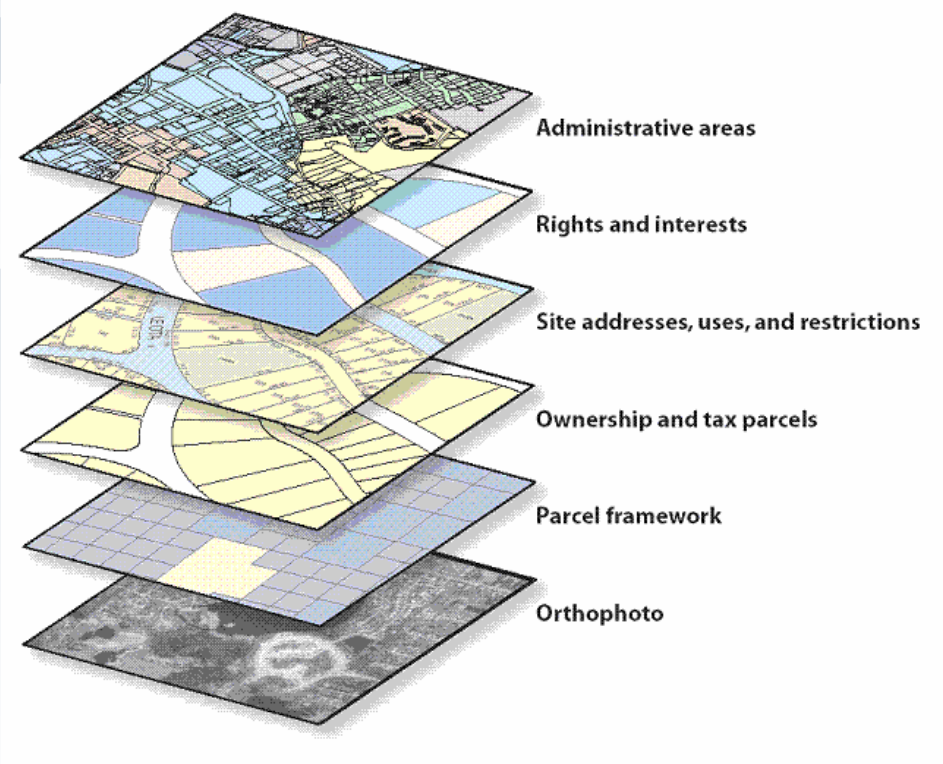
Data Models

- Vector model
  - information about points, lines, and polygons, e.g. roads & highways
  - encoded and stored as a collection of *x*,*y* coordinates
- Raster Model
  - models continuous features
  - a collection of grid cells
  - e.g. aerial photo



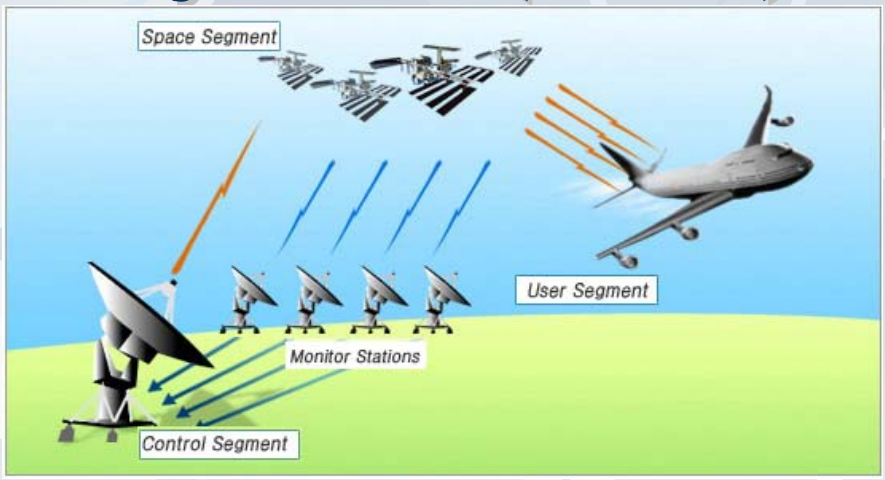
GIS Applications

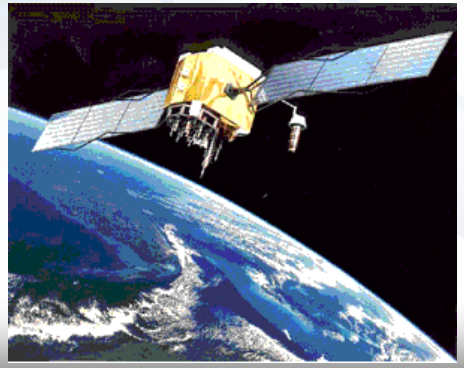
- Data stored in a database
- Allows for spatial analysis--e.g. spatial queries
- Enable data visualization of selected spatial and non-spatial data to:
  - solve complex problems
  - view status and trends
  - track assets
  - track vehicles
  - decision support

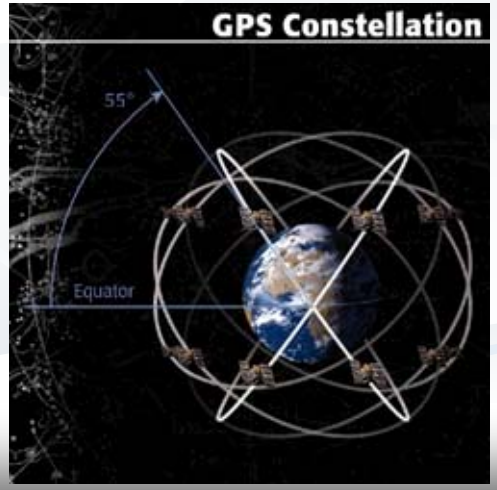


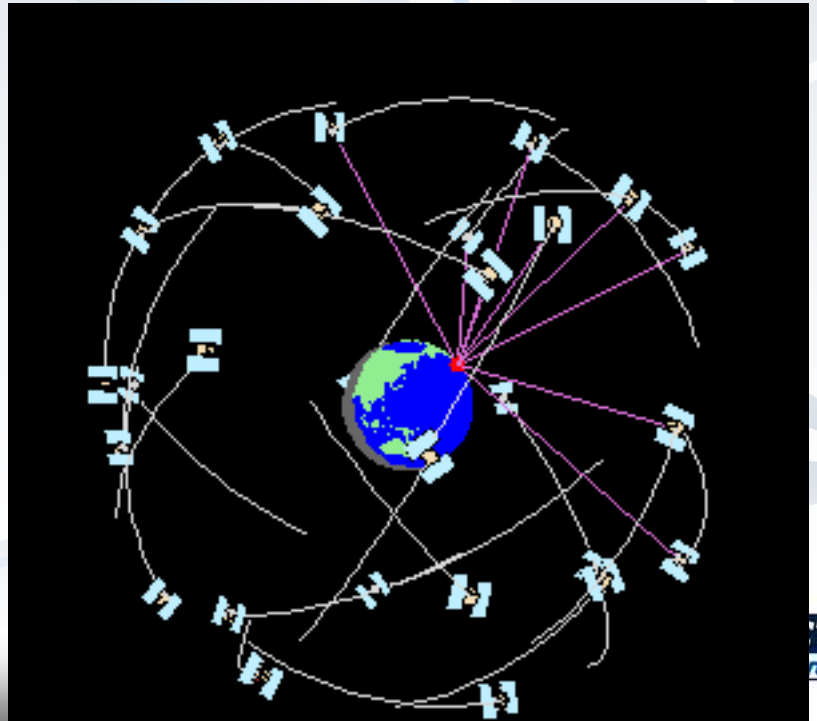
Global Position System (GPS)

- Consists of 3 Segments:
- Space Segment:
  - 30 GPS Satellites (6 spares) in 6 orbital planes, 55 degree inclinations
  - 20,200 km, 12 hrs orbits



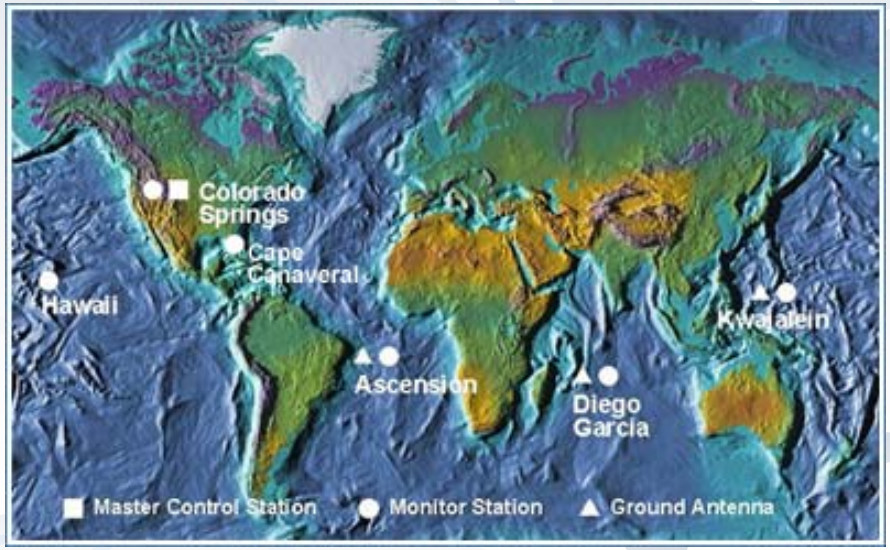






GPS Control Segment

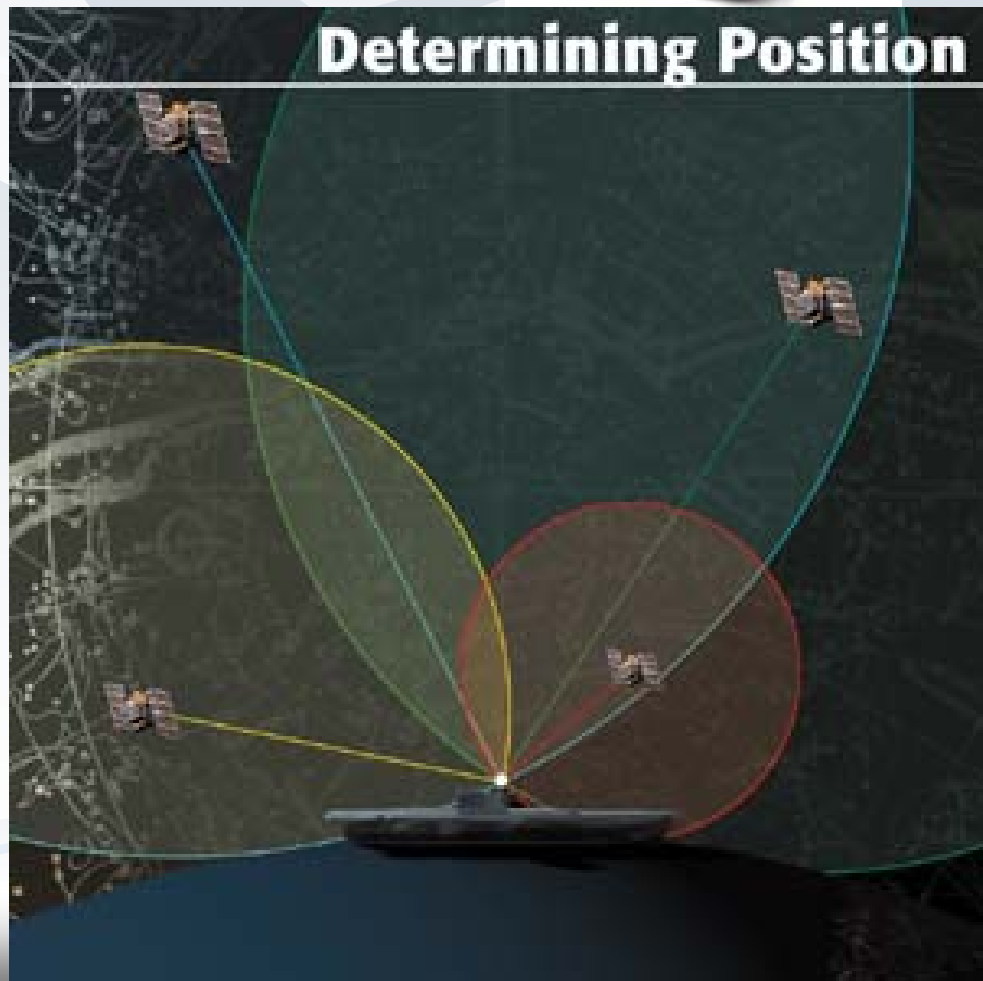
- Master Control Station (MCS)
  - located in the Consolidated Space Operations Center (CSOC) at Schriever Air Force Base (SAFB), CO.
  - manned 24 hours per day, 7 days per week
  - GPS ephemeris being a tabulation of computed positions, velocities and derived right ascension and declination of GPS satellites at specific times, replace "position" with "ephemeris"
  - The prediction data is up-linked, or transmitted, to the satellites for transmission back to the users.
  - The control segment also ensures that the GPS satellite orbits and clocks remain within acceptable limits.
- Monitor Stations
  - Six monitor stations
  - Each monitor the exact altitude, position, speed, and overall health of the satellites.
- Ground Antennas:
  - Monitor and track the satellites.
  - Transmit correction information to individual satellites.



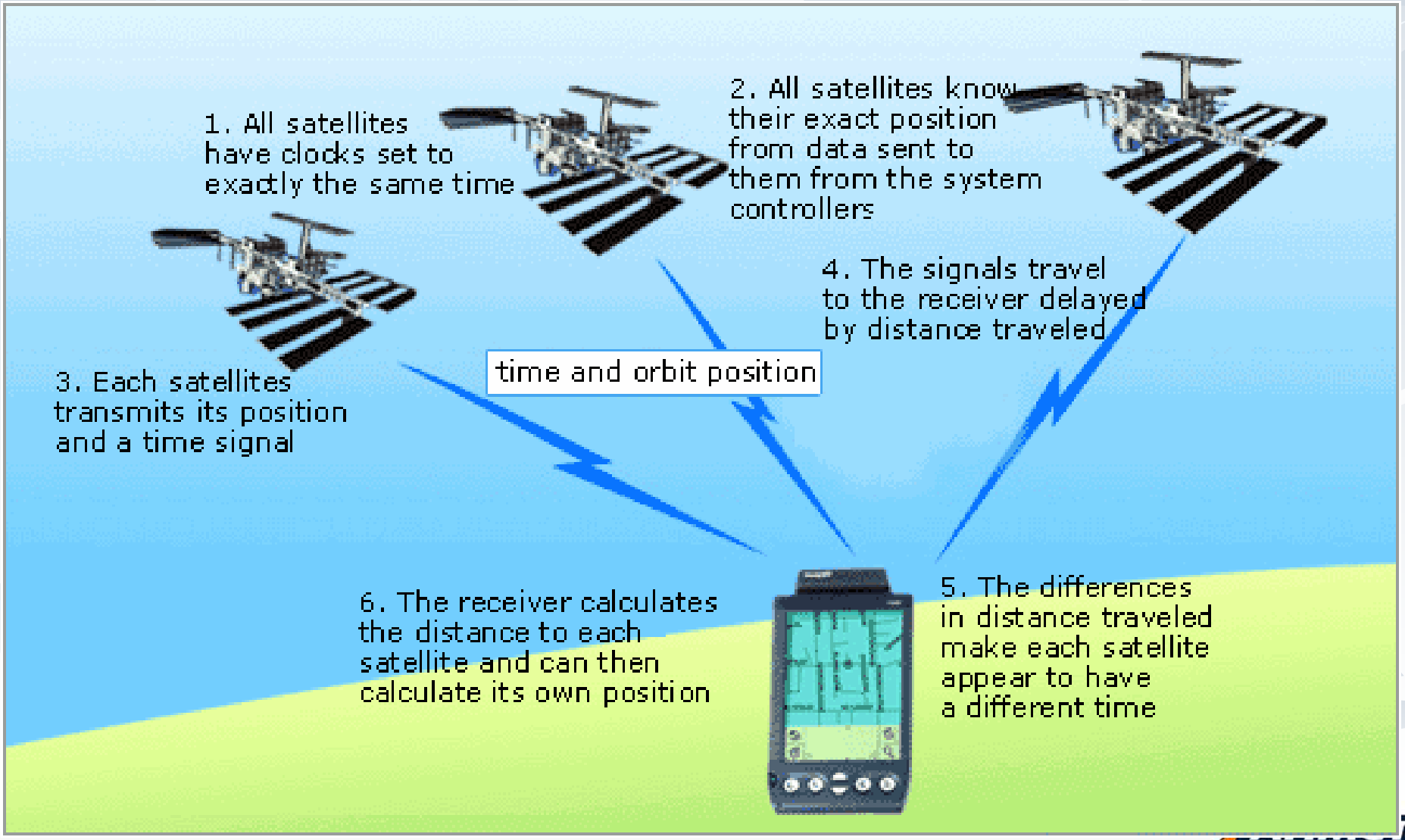
GPS Control Segment Locations

User Segment

- Consists of antenna for receiving GPS satellite signals,
- And a GPS receiver for collecting navigation data and for calculating time and location



GPS Operation

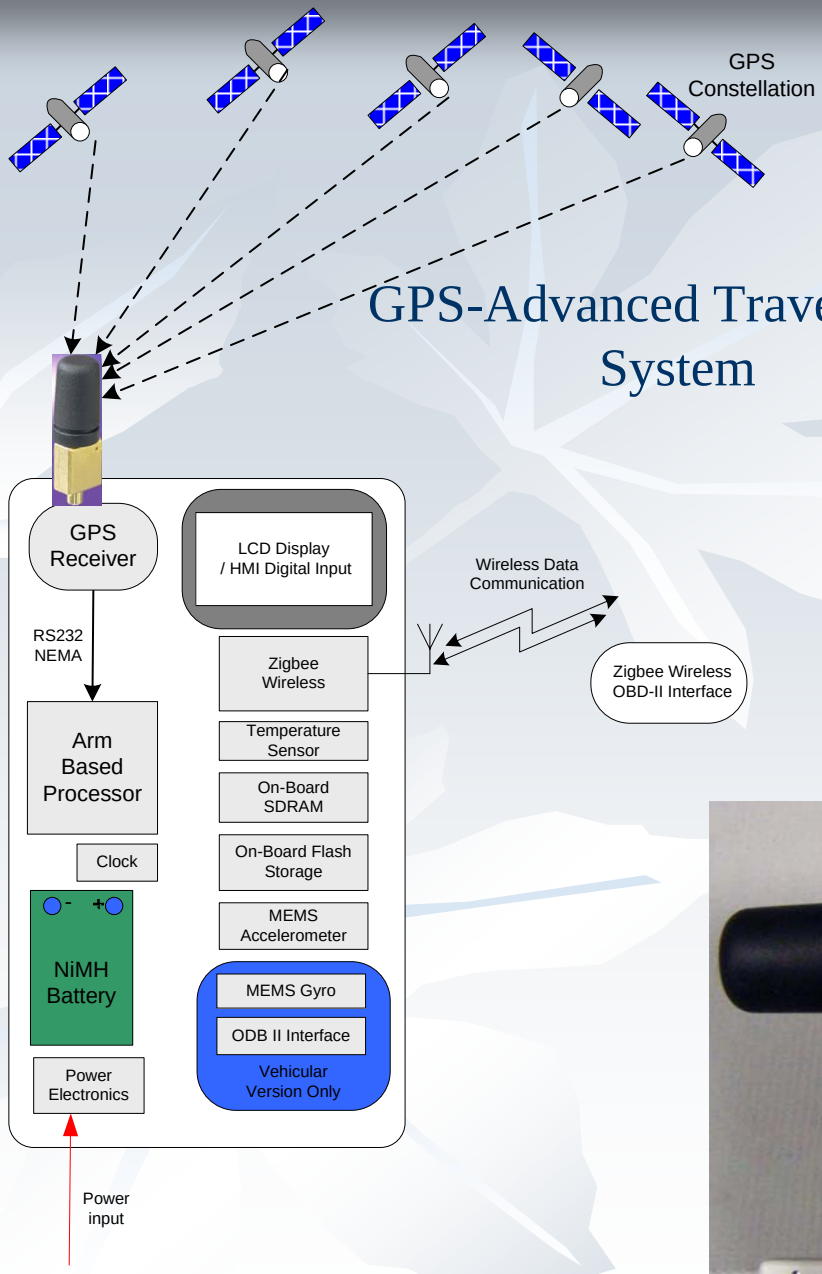


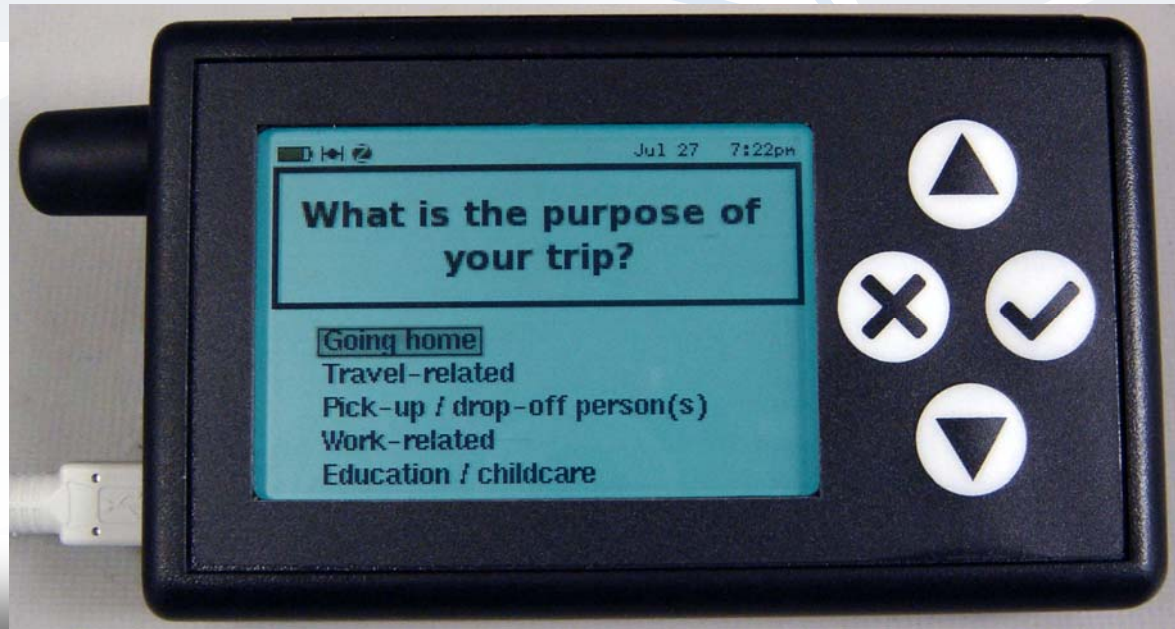
DGPS Accuracy Comparison

	No Differential	Beacon	Omnistar	WAAS	Omnistar HP
Latitude Standard Deviation (m)	1.49	0.35	0.39	0.38	0.05
Longitude Standard Deviation (m)	1.13	0.27	0.31	0.30	0.06
Elevation Standard Deviation (m)	3.23	0.75	0.65	0.78	0.12
Latitude Range (m)	15.98	5.86	3.67	7.74	0.57
Longitude Range (m)	14.47	3.97	2.41	4.77	0.54
Elevation Range (m)	35.29	9.11	5.55	14.93	1.20
% Time without differential	100.00	0.09	0.00	0.05	0.00

Example of GIS/GPS Integration

GPS-Advanced Travel Diary System

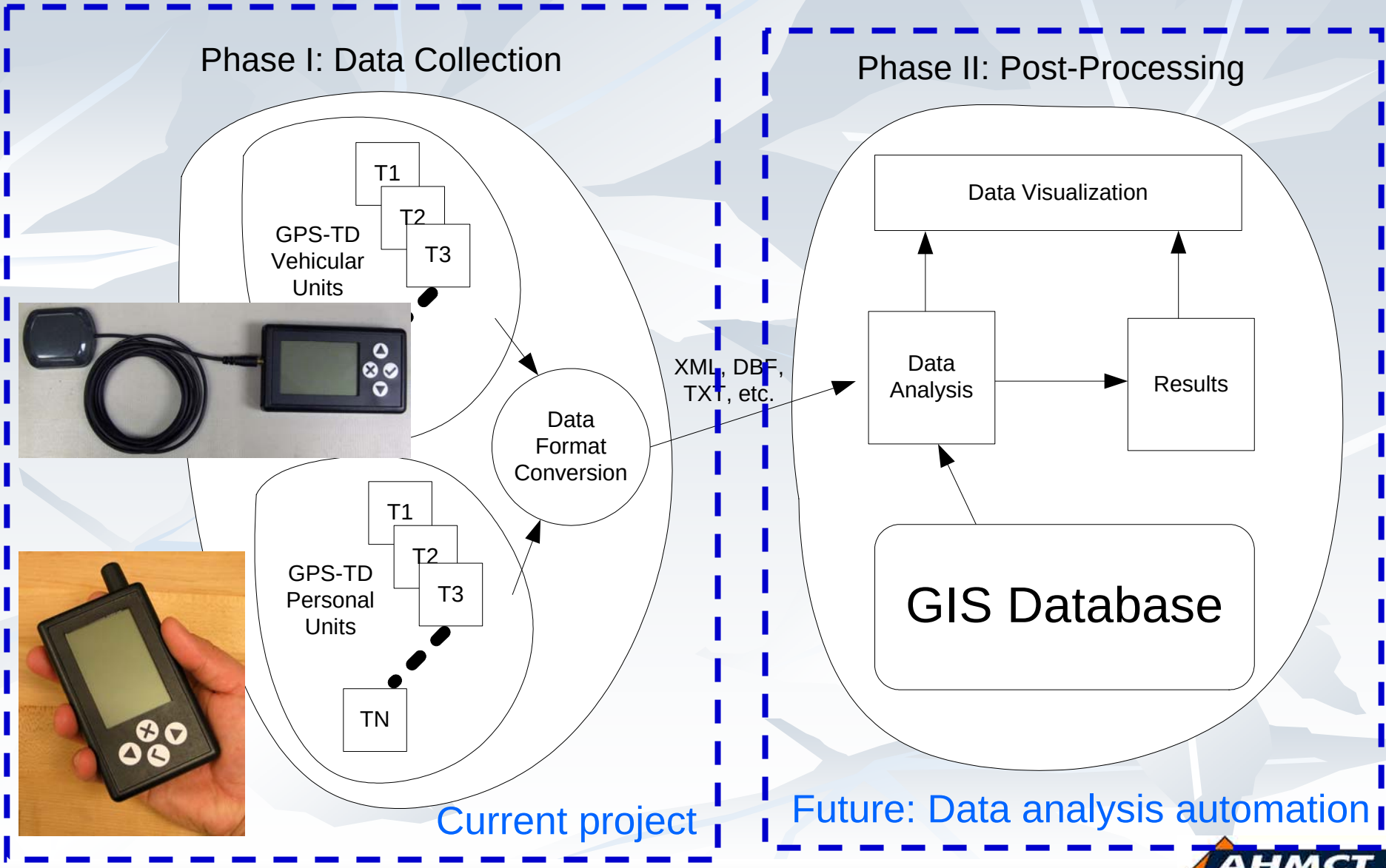




Goals of Travel Surveys

- Provide data to calibrate regional models and travel demand models
- Develop travel demand models to forecast future demand
- Predict the number of trips generated by households as a function of demographics, socioeconomics, and location relative to employment and commercial centers
- Estimate travel mode choice and traffic volumes on various roads
- Assess the impact of changes in transportation policy or the transportation system
- Predict emissions from motor vehicles and input for air quality analysis
- Thus, enhance transportation planning with improved knowledge of traveler behavior
- Department of Transportation, State, County, and City planners will use data and models for infrastructure planning and deployment

System Architecture



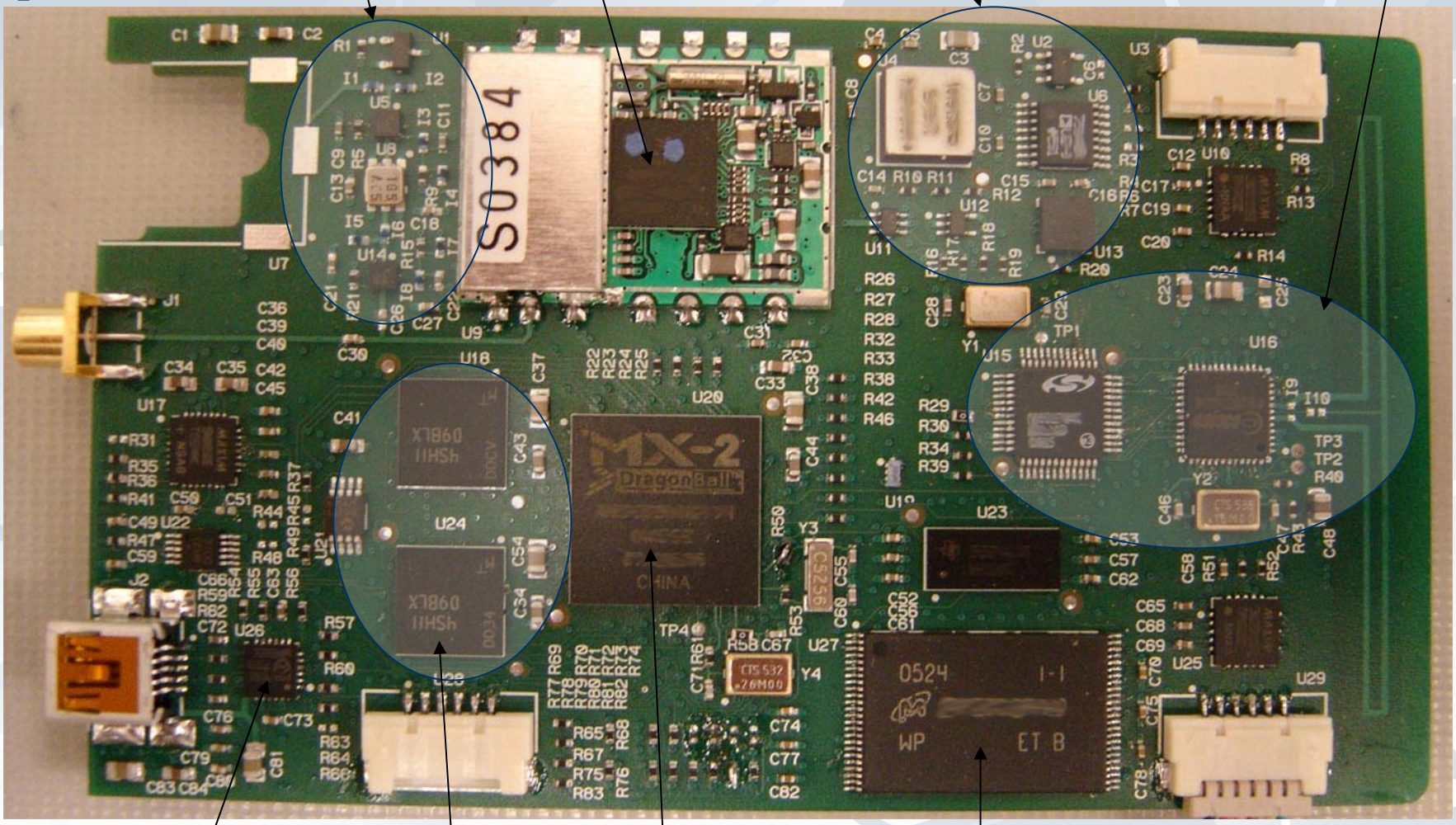
6-layer board
130 components
470 parts

GPS RF

GPS Module

Gyro & Accelerometer

ZigBee Wireless

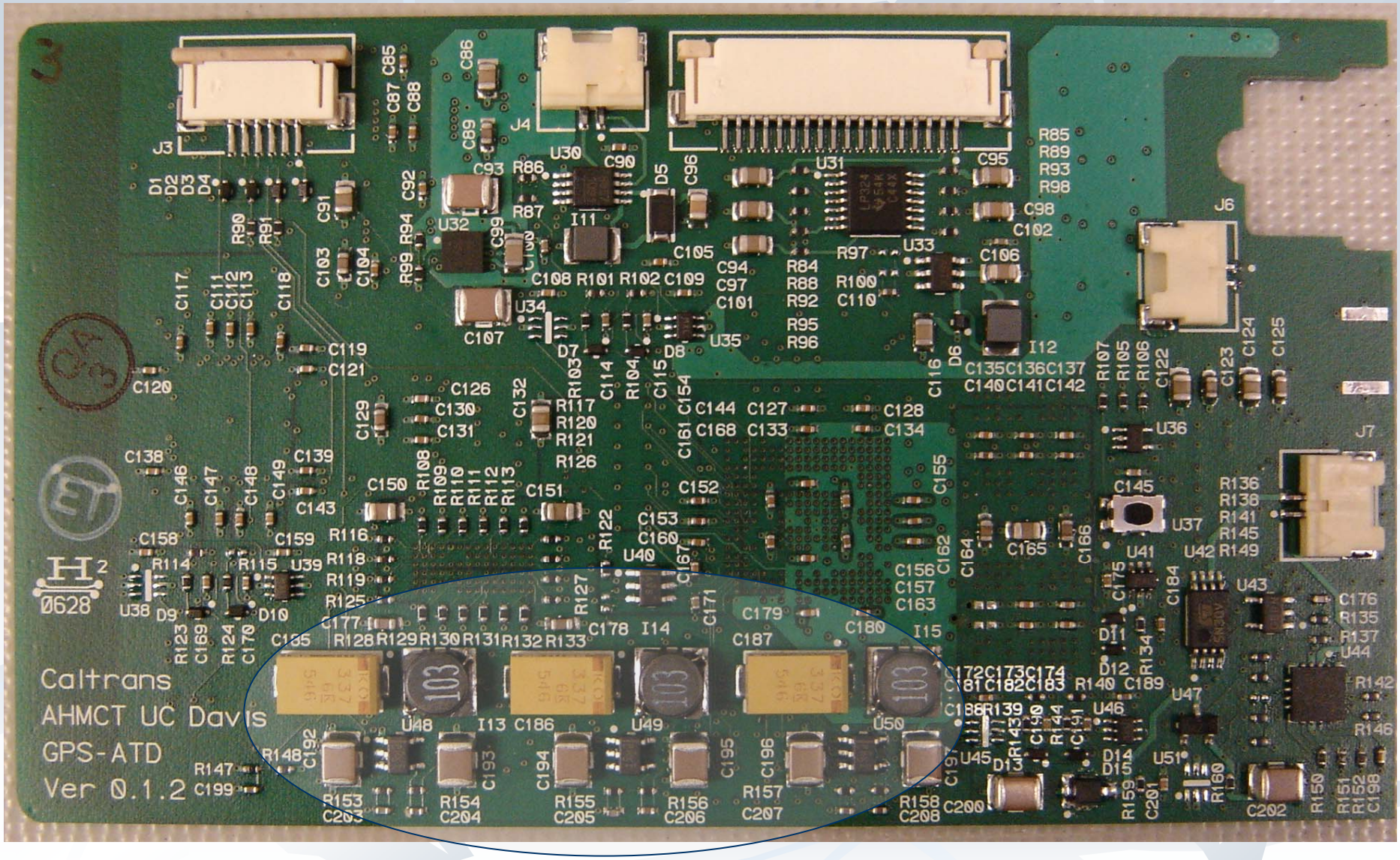


USB

SDRAM

CPU

256MB NAND Flash



Power Supplies

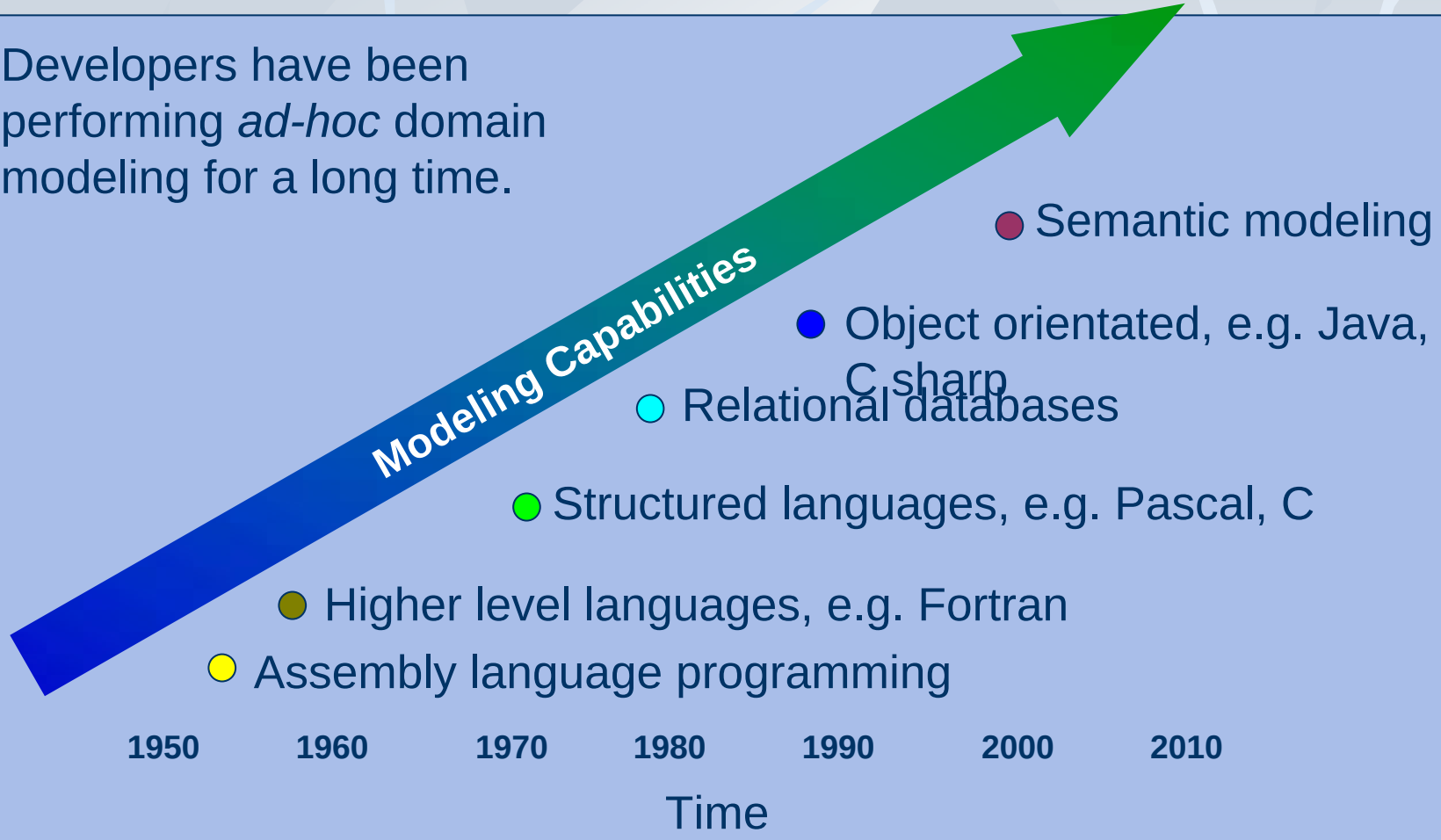
Project Objectives

- To reduce the user-burden of traditional diaries that has resulted in the participants' omission of trips.
- To provide activity-time-space diaries showing the relationship between trips, land use activities, and time.
- To collect accurate and reliable travel behavior information to support planning models and other analysis.
- Overcome challenges and pitfalls encountered in previous GPS-aided longitudinal travel surveys
  - Long GPS startup time
  - GPS outage in Urban Canyons and under tree canopies
  - Hardware robustness

Example of GPS, GIS, Data Bases, and Visualization Integration

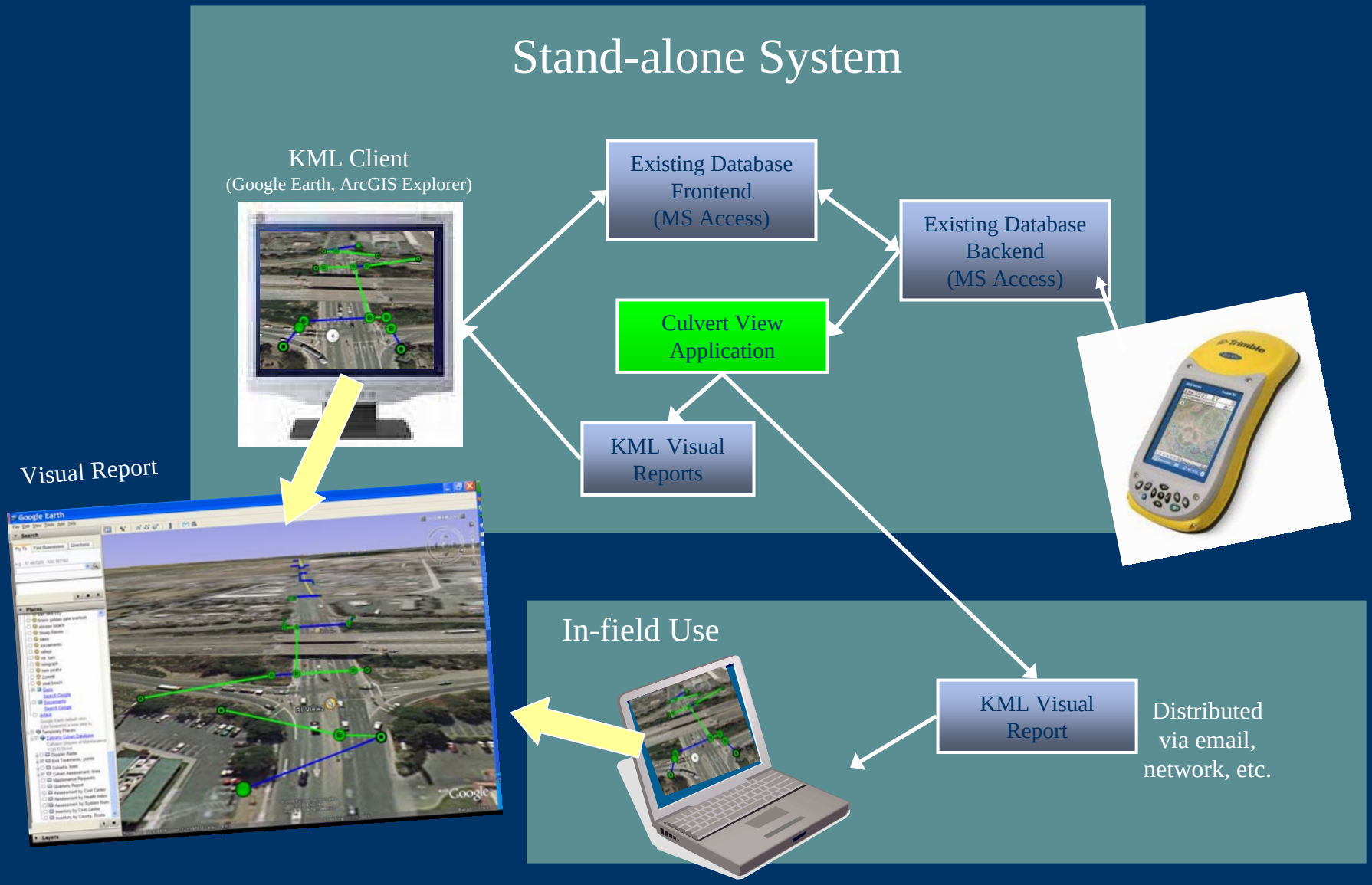
Modeling Capabilities Over Time

Developers have been performing *ad-hoc* domain modeling for a long time.

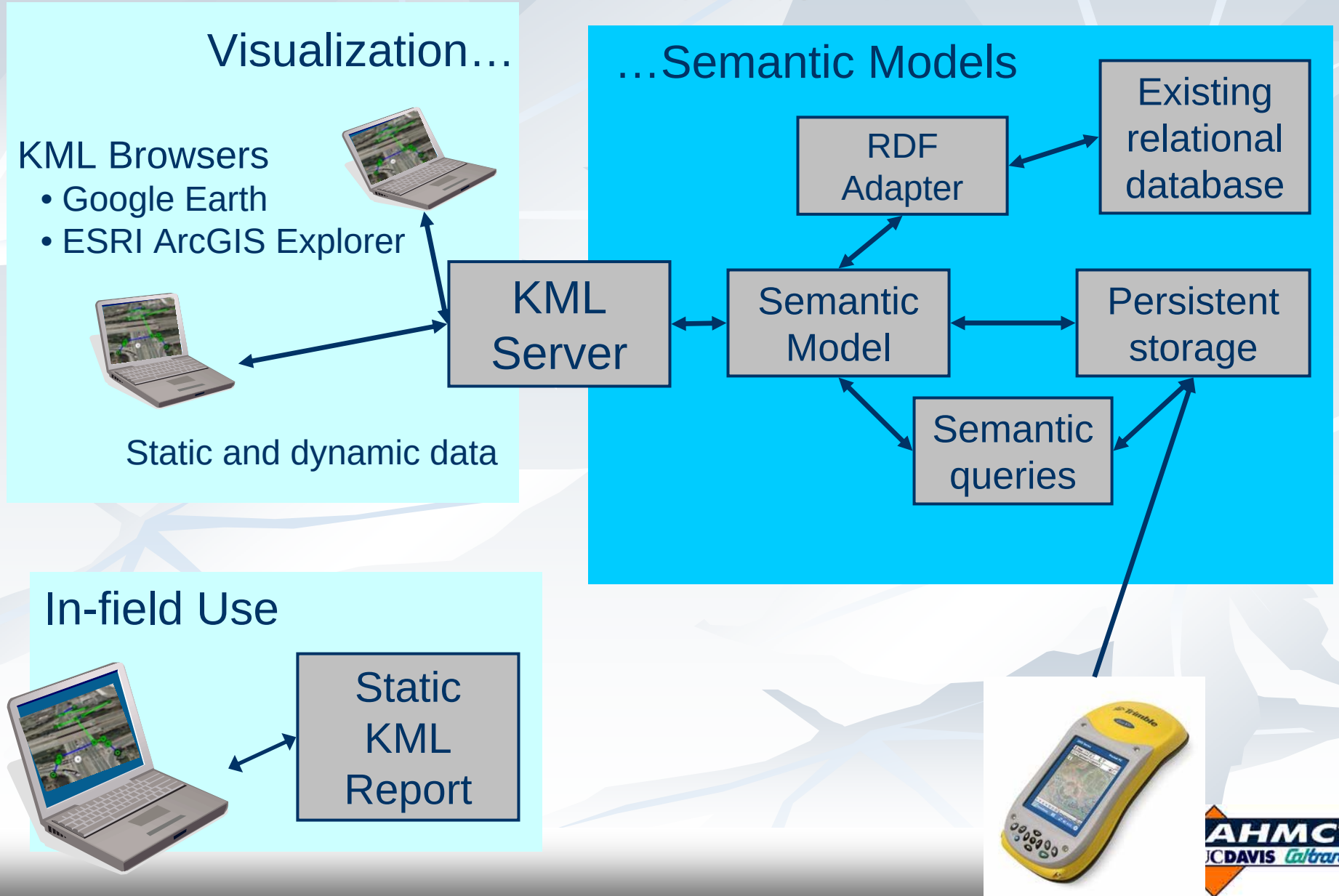


Semantic modeling is essentially strong OO modeling without the implementation (methods)

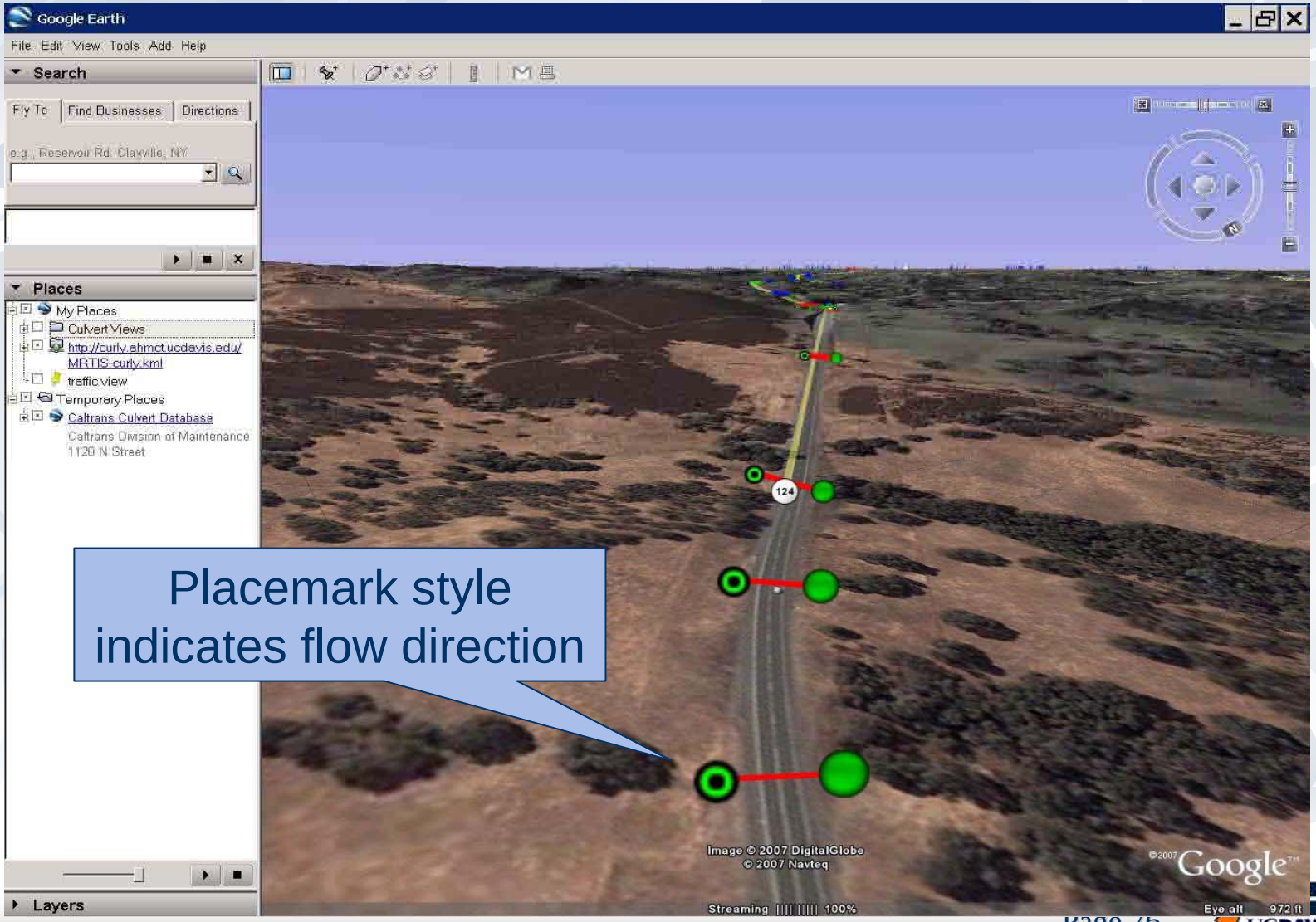
Roadside Inventory
Stand-alone Visualization Architecture – *Working Prototype Demonstrated*



Roadside Inventory Digital Architecture



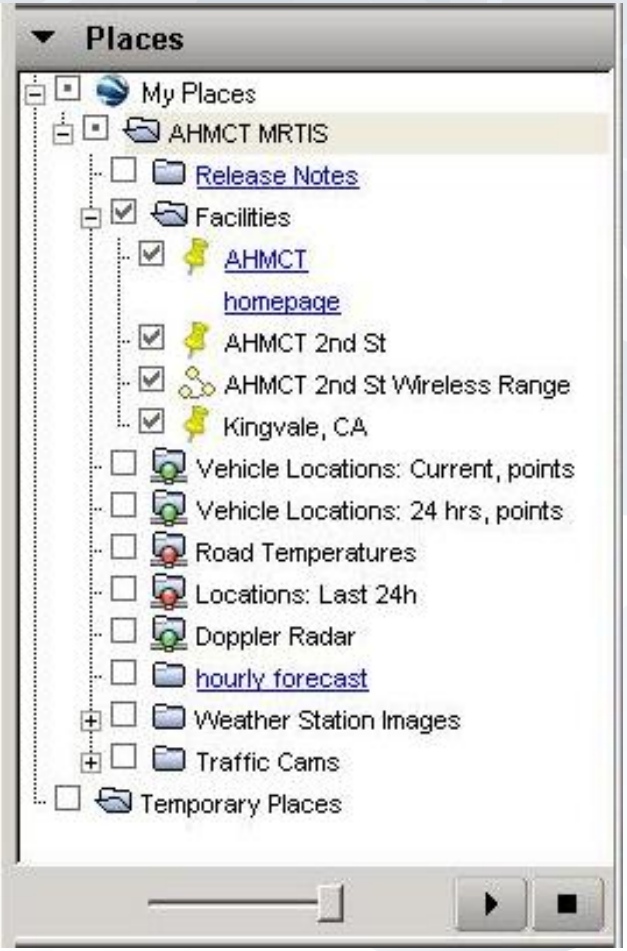
Roadside Inventory
Terrain Model + Culverts

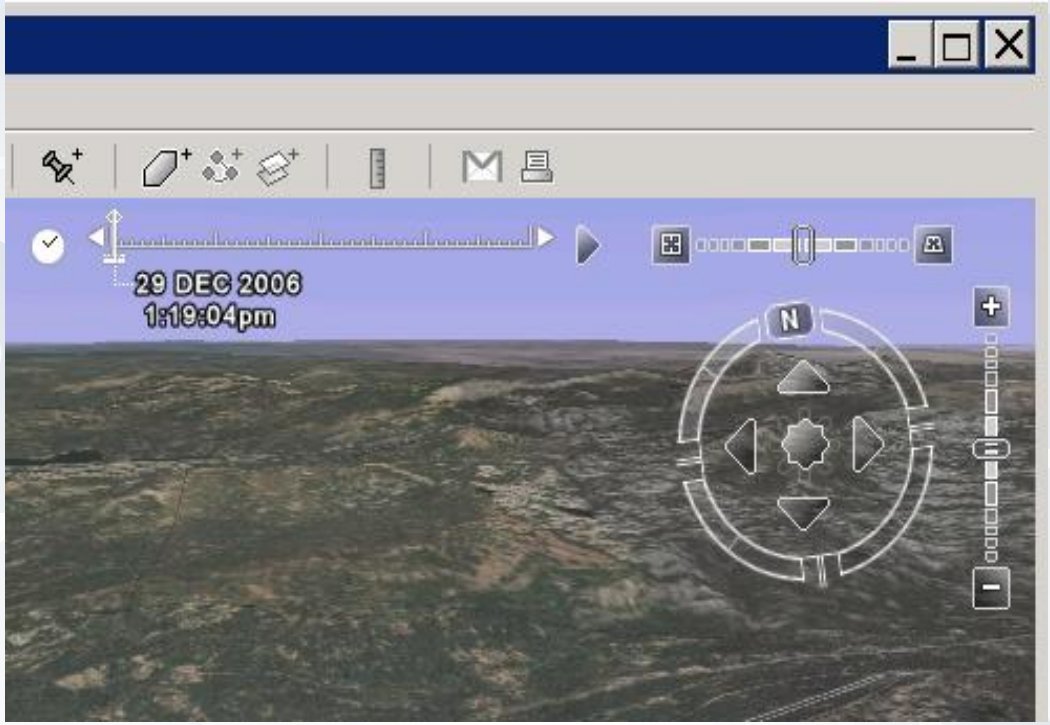


Placemark style indicates flow direction

Visualization Across Three Domains

Physical + Time + Space

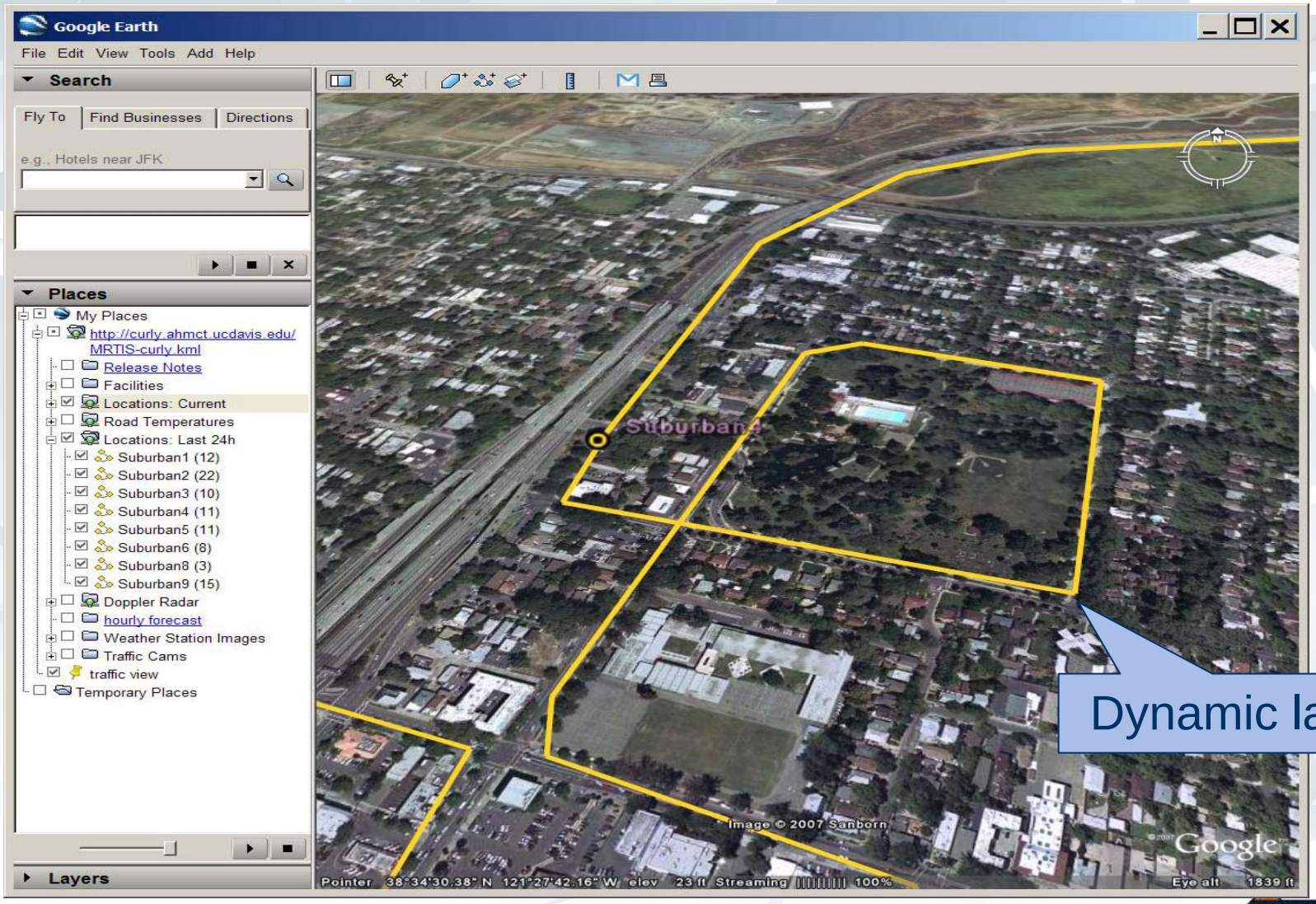




Visualization is supported by semantic & relational queries on back-end.

Vehicle Location

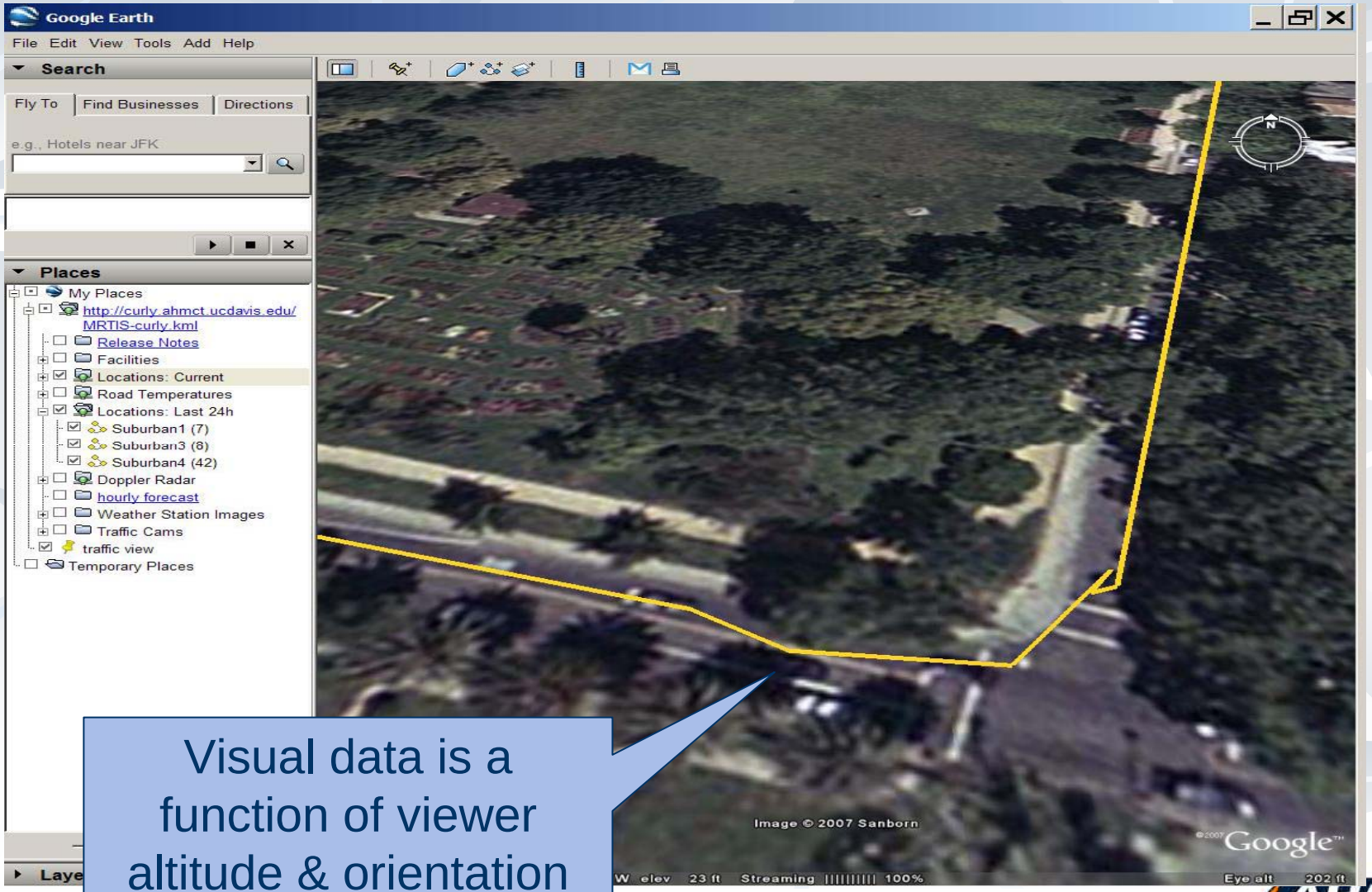
Real-time and Historic GPS Sensor Data



Dynamic layer

Dynamic Visualization

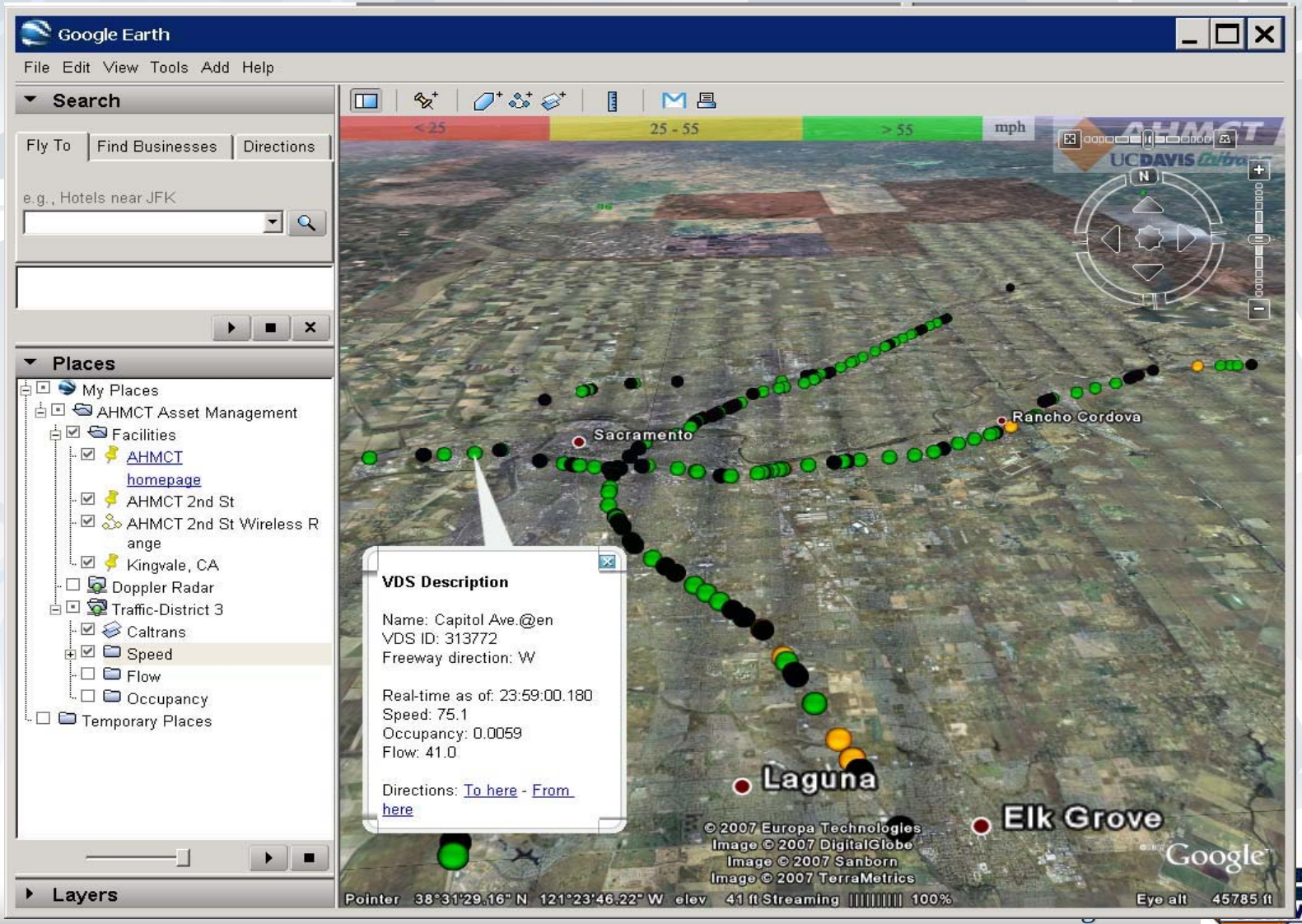
Multi-resolution GPS Data



Visual data is a function of viewer altitude & orientation

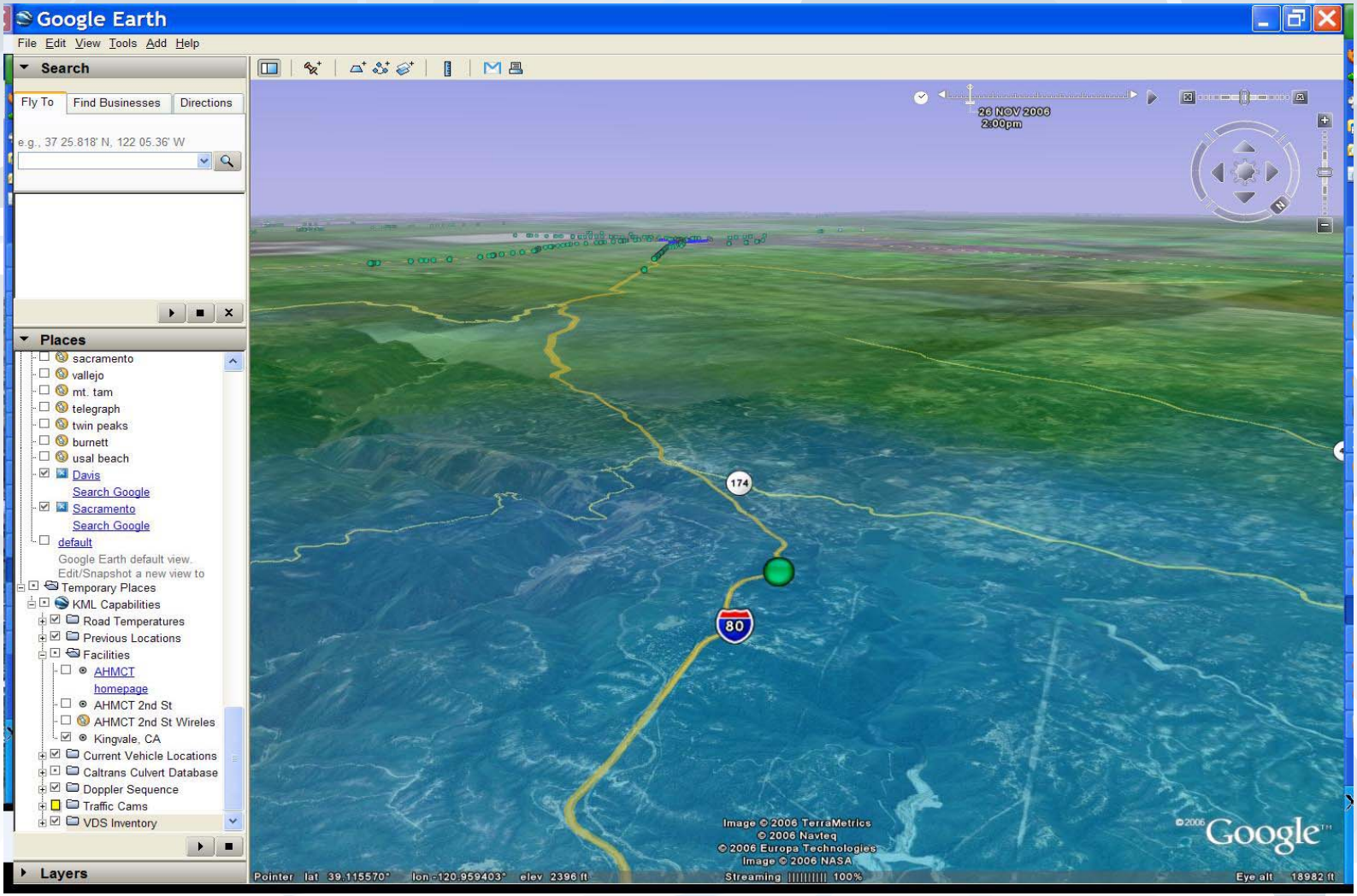
Traffic Visualization

Real-time Speed, Occupancy, Flow



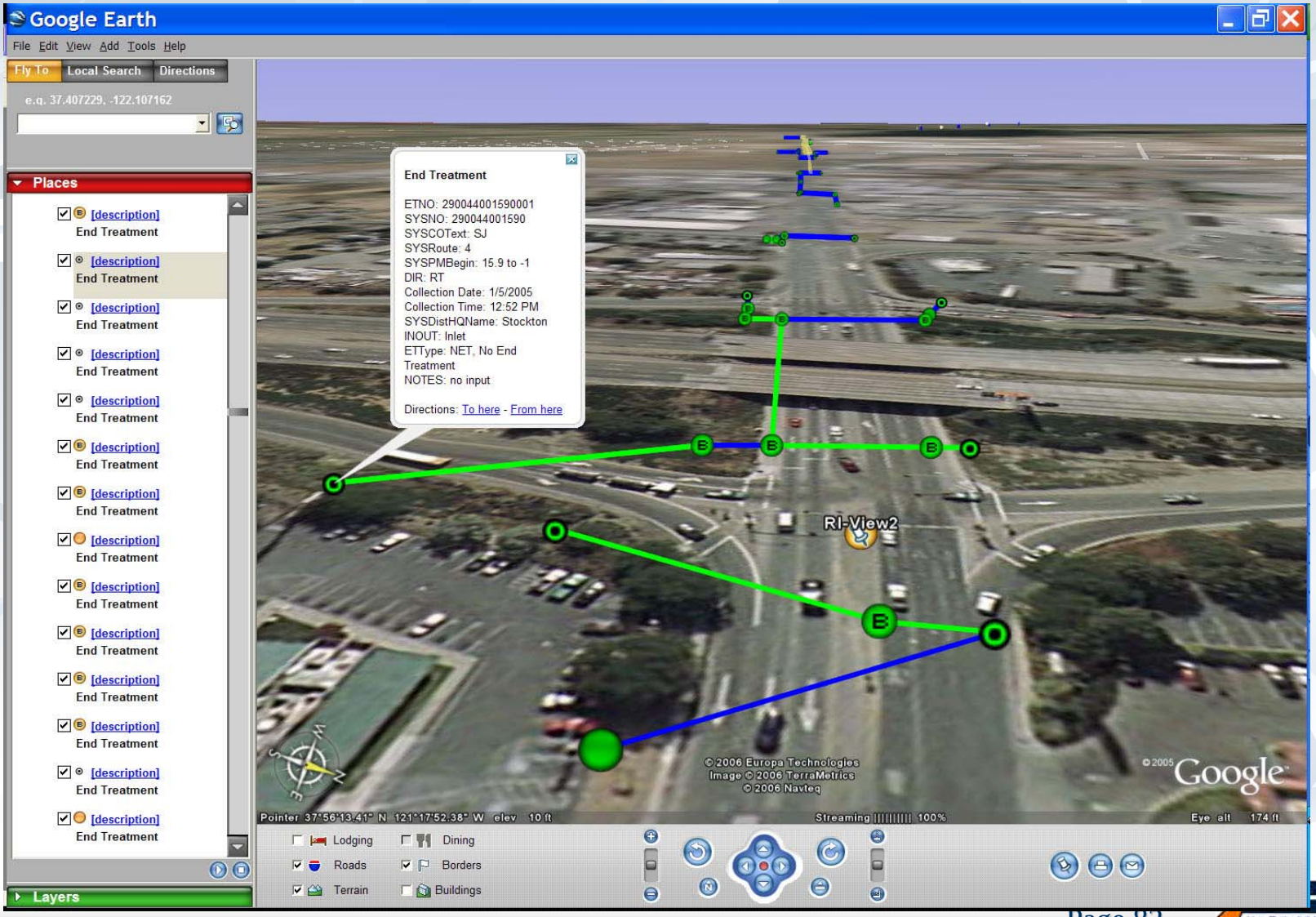
Doppler Radar Terrain Overlays

Real-time and Historic, Radar Loops



http://fish.ahmct.ucdavis.edu/assetman/ahmct-assetman.kml

Asset Properties
Visual Culvert Condition Report



Assets Details in Context

Properties

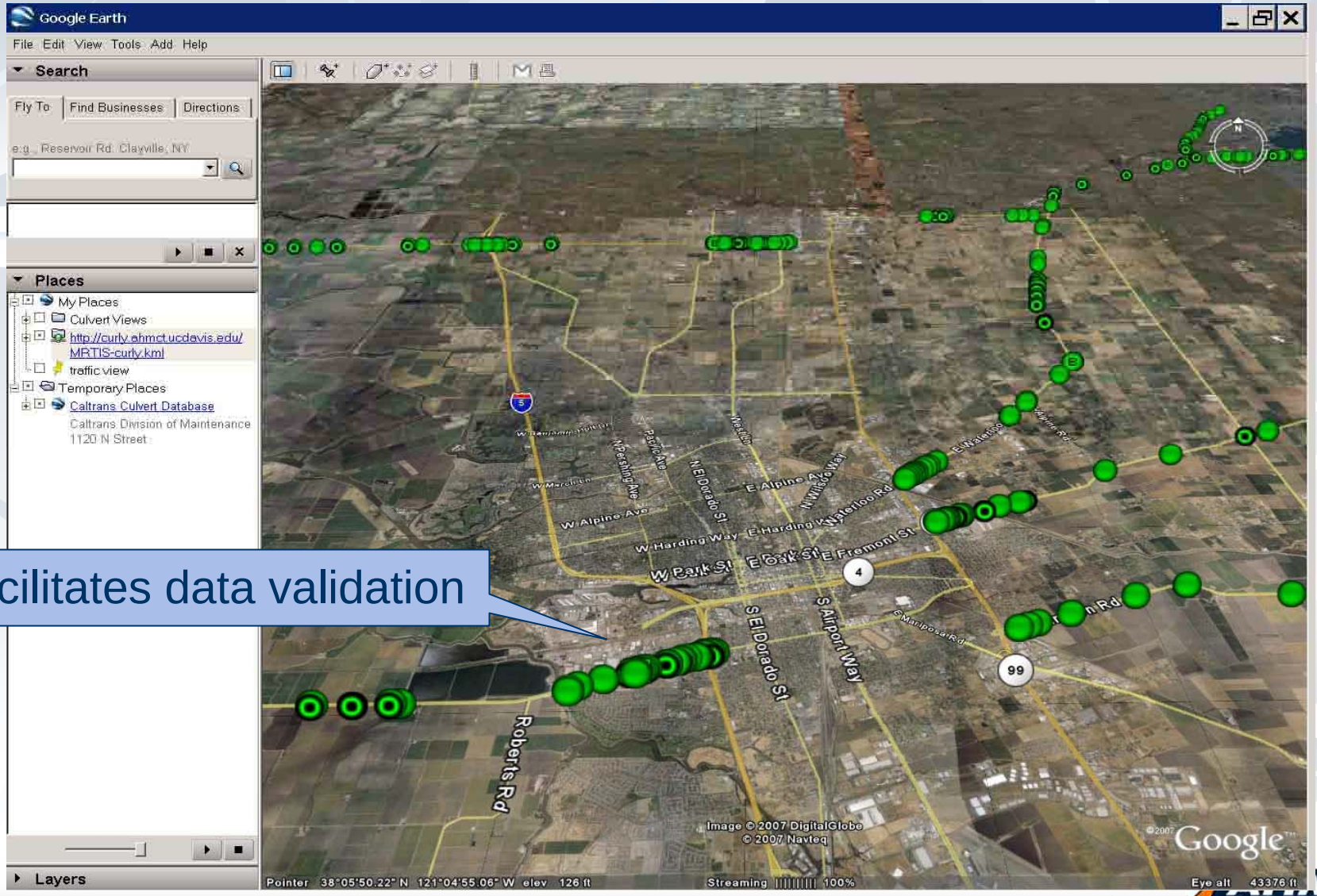
Geo & Time Referenced Photos

Application links

Schedule Maintenance

Culvert Inventory Visualization

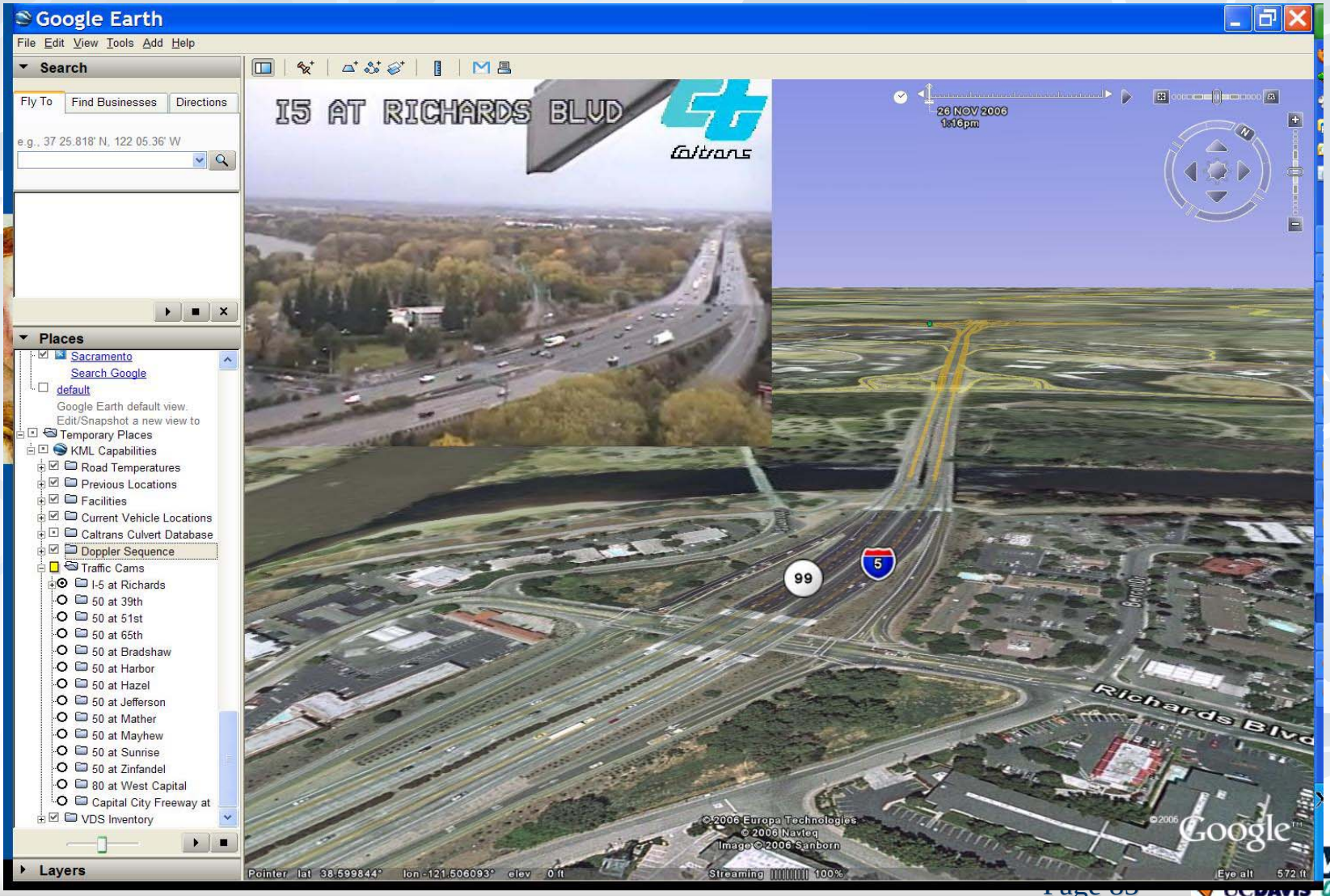
Static Layer

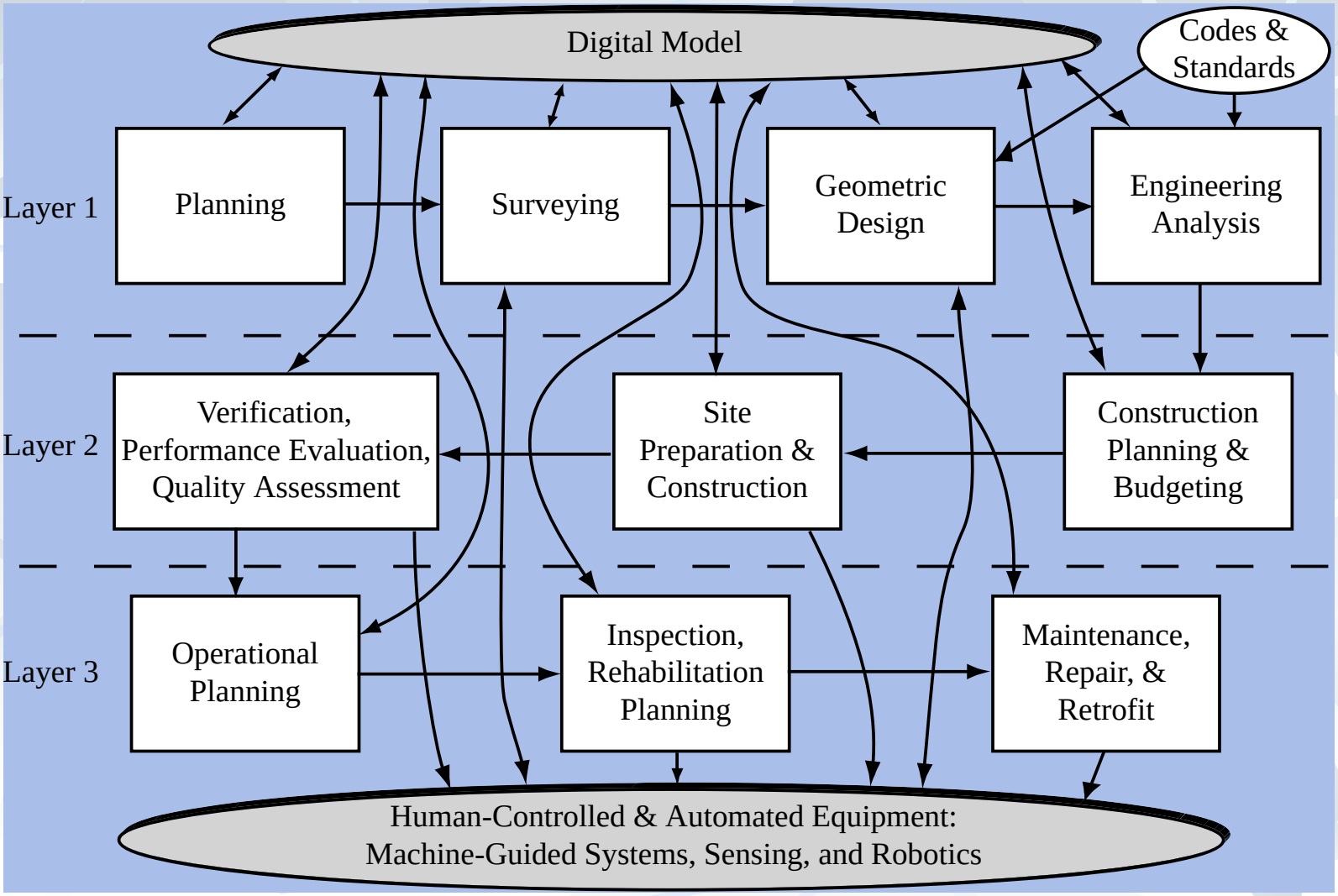


Facilitates data validation

Traffic Cam Overlays

Real-time and historic



Future

Digital Model-Based Planning & Automation