Memorandum

DATE  October 22, 2009

TO  Honorable Members of the Quality of Life Committee: Pauline Medrano (Chair), Voncie Jones Hill (Vice Chair), Carolyn R. Davis, Angela Hunt, Sheffie Kadane, David A. Neumann, Steve Salazar

SUBJECT  Urban Forestry Inventory Using Concurrent Airborne LiDAR & Hyperspectral Remote Sensing

On Monday, October 26, 2009, you will be briefed on the Urban Forestry Inventory. The briefing will be presented by Steve Houser, Chair of the Dallas Urban Forest Advisory Committee and Dr. Fang Qiu, Associate Professor at the University of Texas at Dallas. The briefing material is attached for your review.

If you have questions or need additional information, please let me know.

Forest E. Turner
Assistant City Manager

CC:  Honorable Mayor and Members of the City Council
     Mary K. Suhm, City Manager
     Deborah A. Watkins, City Secretary
     Thomas P. Perkins, Jr., City Attorney
     Craig D. Kinton, City Auditor
     Judge C. Victor Lander, Administrative Judge Municipal Court
     Ryan S. Evans, First Assistant City Manager
     A.C. Gonzalez, Assistant City Manager
     Jill A. Jordan, P.E., Assistant City Manager
     David K. Cook, Chief Financial Officer
     Frank Librio, Public Information Office
     Helena Stevens-Thompson, Assistant to the City Manager
Urban Forest Inventory Using LiDAR & Hyperspectral Images

• Larger existing trees provide 60-70 times the benefit of newly planted trees
• Highest priority in managing any urban forest is a complete tree inventory
• Traditional method of inventory involves volunteers surveying only public trees
• These methods were very labor intensive, time consuming and often inaccurate
• Since public trees comprise only 15-20% of the entire urban forest, the traditional method only provides a small part of the picture
Project History

• Since a traditional survey was not ideal, extensive researched was completed which included hyperspectral images (a new type of image)
• Dr. Fang Qiu was asked by the chair if the new images could be used for a complete tree inventory.
• “It may be possible…but it has never been done”
• Chair works diligently to convince others of the value by personally funding the field work portion of the project ($13K) and contributing almost a year of time
• Chair raises over $100K to complete the project
• Chair authorized the project to move forward lacking $30K of the required budget
Dallas on the “Cutting Edge”

• First complete tree inventory ever based on laser scanning and hyperspectral images using highly advanced computer algorithms
• New technology developed by Dr. Qiu and the chair which allows all tree inventory data to be easily accessed and utilized in making critical urban forest management decisions
• This is a first in the history of urban forestry in that someone can now effectively manage ALL trees (public & private) by simply sitting at their computer
• Hyperspectral images can also be used to manage water quality & quantity, street markings or light fixtures and many others relating to existing land cover management (grey & green infrastructure)
Cost and Next Steps

• The projected cost to complete all of the city is 1.25 million for collection and 1.25 million for processing.
• When other city departments understand the potential use of the images in infrastructure management, the cost can be shared and become very economical.
• As the use of hyperspectral images increases in the future, the cost will decrease.
• Brief other departments on the potential uses.
• Brief NCTCOG, EPA, Texas Forest Service and others to gain backing & financial support in completing a city & regional tree inventory & infrastructure mapping project.
Urban Forestry Inventory using Concurrent Airborne LiDAR and Hyperspectral Remote Sensing

Fang Qiu

University of Texas as Dallas

Sponsored by

Dallas Urban Forest Advisory Committee
Outline

- Study area
- Remote Sensing Data Collection
  - LiDAR, Hyperspectral
- Field Data Collection and Analysis
  - In situ spectroradiometer data collection and analysis
  - Field tree specie, GPS location collection
- LiDAR Data Filtering
  - Segmentation and DTM generation
  - Ground/non-ground separation
- LiDAR Tree Mass Point Extraction
  - Hyperspectral NDVI
Outline

- Urban Tree Top (UTT) Identification
  - Tree Top Climbing
  - Tree height

- Urban Tree Canopy (UTC) Delineation
  - Donut Expanding and Sliding – Canopy Diameter
  - Base height, crown depth

- Urban Tree Species (UTS) Identification
  - Neuro-fuzzy classification

- Digital 3D Tree Canopy Model Construction
  - Individual Tree Modeling
Study Area

- City of Dallas
  - Two pilot study sites, with a total area of 20 square miles
Remote Sensing Data Collection

- Terra Remote Sensing, Inc (TRSI)
  - Sydney, British Columbia, Canada
- Mission partner at University of Victoria
- Date: September, 23-24, 2008
- Aircraft Type: Piper Navajo
  - Altitude: 960 m and 1260 m
  - Flying air speed: 235km/hr
- Total Data Volume
  - Hyper-Spectral Imaging Data: 181 GB
    - Radiance (60.6 GB) + Reflectance (121 GB)
  - LiDAR Data: 3.4 GB
    - 64 GB after uncompressed
LiDAR Data

- Terrain Scanning Laser System
- LiDAR Point Cloud Density
  - (Average Spacing: $1/D^{1/2}$)
  - 9/23/2008: 2 pts/m² (0.7 m)
    - Due to overlap, 3.5 pts/m² (0.53 m)
  - 9/24/2008: 1.25 pts/m² (0.89 m)
    - Due to overlap, 2 pts/m² (0.7 m)
- %Overlap: 80
- Number of Returns: 2
  - First and Last Returns
- Bandwidth: 1064 nm
- Beam divergence: 0.45 mrad
LiDAR Data

3D visualization of elevation of LiDAR points over the Reverchon park study area
LiDAR Data: Turtle Creek Corridor

3D visualization of elevation of LiDAR points over the Turtle Creek Corridor
Hyper-spectral Imaging (HSI) Data

- AISA DUAL HSI Sensor Spectral Imaging Ltd. Finland
  - Simultaneous acquisition of VNIR and SWIR data
    - AisaEAGLE (VNIR)
    - AisaHawk (SWIR)
  - 492 Band (400-2500 nm)
    - VNIR (400-970 nm, 2.44 nm)
    - SWIR (970-2500 nm, 6.28 nm)
- Spatial Resolution
  - 9/23/2008: 1.2 m
  - 9/24/2008: 1.6 m
- Sidelap: 22%
Mosaic of HSI

- **Color Infrared Composite Image**
  - Red: 841.13 nm
  - Green: 677.11 nm
  - Blue: 561.66 nm

- **Typical Colors**
  - Trees: Red
  - Buildings: Cyan
  - Water: Blue/black
In Situ Spectroradiometer Data Collection

- **FieldSpec Pro ASD Spectroradiometer**
  - Spectral Range from 350 – 2500 nm
  - Spectral Sampling of 1.4 nm in 350-1050 nm and 2nm in 1050-2050 nm range resulting in 2151 bands
  - Scan time of less than 3 seconds

![Spectroradiometer](image1)

![High Intensity Contact Probe](image2)
In Situ Spectroradiometer Data Collection

- Sampling areas
  - Reverchon park
  - Turtle Creek area
Reflectance Spectral Signature for 50 species

Mean Spectral Profile for each species used as Reference Spectra
Species Spectral Separability analysis

Using GFLVQ approach (50 Testing Samples)

- About 60-72% of accuracy was achieved
- Double the % accuracy of the spectral angle mapping

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<th>Accuracy</th>
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<td>4</td>
<td>68%</td>
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<td>5</td>
<td>64%</td>
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<td>6</td>
<td>60%</td>
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<td>7</td>
<td>70%</td>
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<tr>
<td>8</td>
<td>72%</td>
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<tr>
<td>9</td>
<td>68%</td>
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<tr>
<td>10</td>
<td>70%</td>
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<td>34%</td>
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<td>2</td>
<td>30%</td>
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<td>10</td>
<td>42%</td>
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Urban Tree Field Survey Data by Halff Association

Turtle Creek Corridor

- Total 2602 trees surveyed.
- Total 46 species found
- 10 most frequently occurring species identified.
LiDAR Data Filtering

- Segmentation using MNN
- Ground and non-ground separation
- Digital Terrain Model generation
Lidar Filtrring
Ground points
Non-ground points
Lidar filtering of ground and non-ground points
LiDAR Data Filtering: Ground points
LiDAR Data Filtering: Non-ground
LiDAR Tree Mass Point Extraction

- Normalized Difference Vegetation Index (NDVI)

\[ NDVI = \frac{\rho_{nir} - \rho_{red}}{\rho_{nir} + \rho_{red}} \]

- Red: 660nm (band 113)
- Near-infrared: 860nm (band 198)
Urban Tree Top Identification & Canopy Delineation
Urban Tree Top: Results
Urban Tree Canopy (UTC) Delineation: Results
Urban Tree Species (UTS) Identification: Results
# Accuracy Assessment

<table>
<thead>
<tr>
<th>Species Name</th>
<th>Accuracy</th>
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<th>Accuracy</th>
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<tbody>
<tr>
<td>American Elm</td>
<td>39.39%</td>
<td>Bois d'arc</td>
<td>91.67%</td>
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<tr>
<td>Hackberry</td>
<td>47.89%</td>
<td>Sycamore</td>
<td>72.73%</td>
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<td>Pecan</td>
<td>65.55%</td>
<td>Black Locust</td>
<td>87.50%</td>
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<td>E. Red Cedar</td>
<td>62.93%</td>
<td>Redbud</td>
<td>100.00%</td>
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<td>Shumard Red Oak</td>
<td>77.27%</td>
<td>Persimmon</td>
<td>100.00%</td>
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<td>Tree of Heaven</td>
<td>76.36%</td>
<td>Slash pine</td>
<td>100.00%</td>
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<td>Cedar Elm</td>
<td>83.54%</td>
<td>Gingko</td>
<td>100.00%</td>
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<td>Green Ash</td>
<td>87.23%</td>
<td>Southern Magnolia</td>
<td>100.00%</td>
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<tr>
<td>Red Mulberry</td>
<td>84.62%</td>
<td>Dogwood</td>
<td>100.00%</td>
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<tr>
<td>Chinaberry</td>
<td>78.79%</td>
<td>White Ash</td>
<td>100.00%</td>
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<tr>
<td>Gum Bumelia</td>
<td>88.89%</td>
<td>Pear</td>
<td>100.00%</td>
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<tr>
<td>Baldcypress</td>
<td>84.00%</td>
<td>Chinese Pistache</td>
<td>100.00%</td>
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<tr>
<td>Cherry Laurel</td>
<td>95.00%</td>
<td>Chinese Tallow</td>
<td>100.00%</td>
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<tr>
<td>Boxelder</td>
<td>90.00%</td>
<td>Southern Catalpa</td>
<td>100.00%</td>
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<tr>
<td>Post Oak</td>
<td>100.00%</td>
<td>Sweetgum</td>
<td>100.00%</td>
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<td>Live Oak</td>
<td>89.47%</td>
<td>Golden Raintree</td>
<td>100.00%</td>
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<tr>
<td>Bur Oak</td>
<td>94.12%</td>
<td>Black Walnut</td>
<td>100.00%</td>
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<tr>
<td></td>
<td>94.12%</td>
<td>Honey Locust</td>
<td>100.00%</td>
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<tr>
<td>Crepe Myrtle</td>
<td>100.00%</td>
<td>Western Soapberry</td>
<td>100.00%</td>
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<tr>
<td>Black</td>
<td>93.75%</td>
<td>Catalpa</td>
<td>66.67%</td>
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<tr>
<td>Kappa</td>
<td>64.4%</td>
<td>Total Accuracy:</td>
<td>68.8%</td>
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</table>
Digital 3D Tree Canopy Model Construction

- Tree top locations \((x_t, y_t)\)
- Tree heights \((z)\)
- Tree base heights \((bh)\)
- Tree crown depths \((ch)\)
- Tree crown radius \((cr)\)

\[
\left(\frac{(z - bh)^n}{ch^n}\right) + \left(\frac{(x - x_t)^n}{cr^n}\right) = 1
\]

\[\begin{cases} 
  n = 1 : \text{conical shape} \\
  n = 2 : \text{elliptical shape}
\end{cases}\]
Tree model: Results
Individual Tree Extraction and Visualization
Individual Tree Structure Model

![Image of Individual Tree Structure Model]

The image shows a software interface with a tree structure model, demonstrating individual tree structures in different layers and colors.