Development of Standard Data Format for 2-Dimensional and 3-Dimensional (2D/3D) Pavement Image Data

Project Progress Report

PI: Kelvin C.P. Wang, Qiang "Joshua" Li, and Cheng Chen
PhD Students: Allen A. Zhang & Ace Y. Fei
School of Civil and Environmental Engineering
Oklahoma State University
405-744-6328
kelvin.wang@okstate.edu

George Chang and Jason Dick
Transtec Group, Inc.

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OKLAHOMA STATE UNIVERSITY

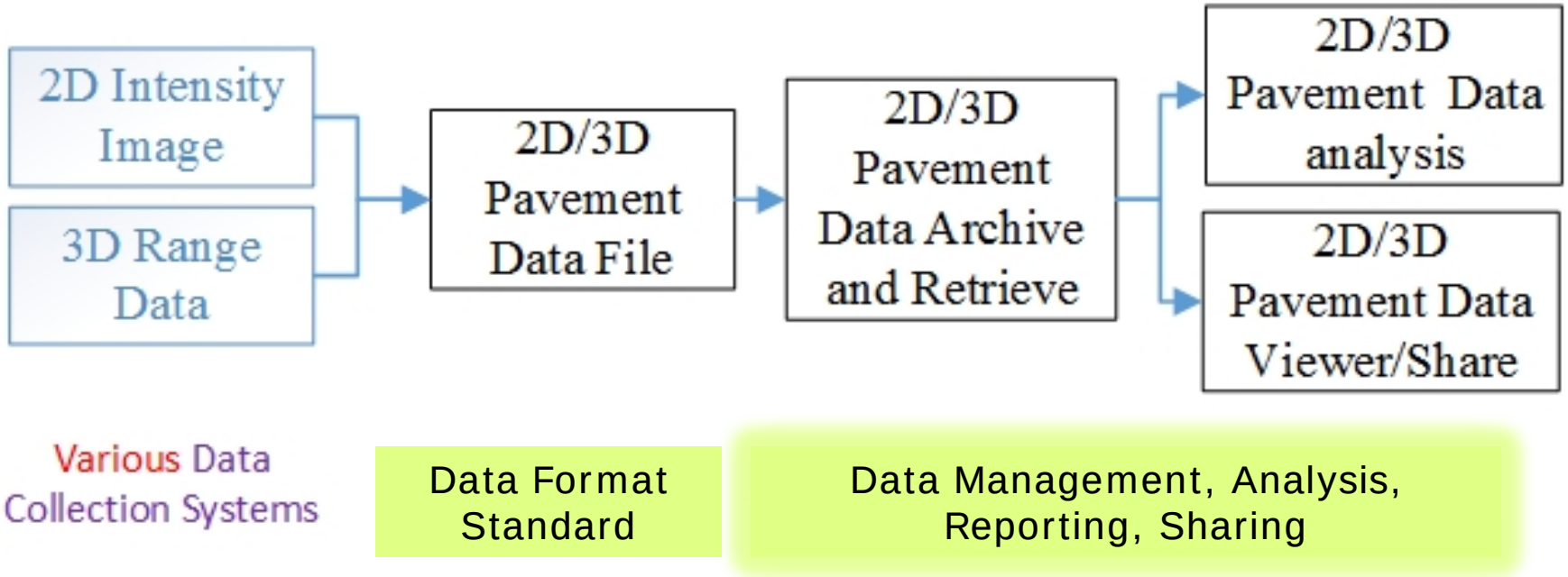
Objective in RFQ

- Establish a recommended standard data format for 2D/3D pavement image data
  - Share various sources of data between users, software tools, & electronic platforms
  - Facilitate workable protocols for condition surveys
  - Promote the demand of new 2D/3D technologies
  - Accelerate the development potential of analysis tools for pavement condition

Objective in RFQ (Cont.)

- Support the structure of the AASHTO standards, separating collection from analysis
- Develop verification protocols in the AASHTO standards
- Use for standard viewer software
- Apply analysis algorithms from anyone to 2D/3D digital images from different sources

Pavement Imaging Data Flow



Project Tasks

- Task 1—Kickoff Meeting
- Task 2—Research Current Practices
- Task 3—Evaluate Data Items and Formats
- Task 4—Develop Metadata and Proposed Standards

Task 1 Kickoff Meeting

- Completed on August 7, 2015

Task 2 Study Current Practices

- Review Common Pavement Image Data and Data Formats (**Completed**)
  - Data collection technology; Data items collected and protocols
  - Data format; Data management practices
- Survey of TPF-5(299) Participating Highway Agencies & Suppliers (**Completed**)
- The Project Panel
  - Reviewed & provided comments on the reports
  - Several times required further investigation and assessment through out the project

2D Data Format

- Uncompressed format: BMP
- Compressed formats
  - PNG
  - GIF
  - TIFF
  - GeoTIFF
  - **JPEG (widely used)**
  - JPEG successors: BPG, JPEG-XR, **JPEG 2000 (widely used)**, PGF

3D Data Format

- No open standard for 3D pavement surface data
- By computer graphics community (140+ formats)
  - Universal 3D (U3D) specification (Ecma International)
  - ASTM E57 file format
  - 3DFC

3D Data Format

- By highway agencies & equipment suppliers
  - Mostly proprietary or ad-hoc formats
  - **HiSPEQ** Project (Europe 2015): various survey data, primarily 2D image but not 16-bit 3D data
  - **File Exchange Format** (FEF): Tsai (2014) for line laser imaging data for Remote Sensing & GIS
  - **Open Curved Regular Grid (OpenCRG®)**: detailed road surfaces for tire pavement interaction simulation
  - **LandXML**: highway geometric data for the exchange of civil design information between software applications
  - **"Elementary Data" format**: by the Germany Federal Road Authorities in 2005 to index 2D, profiles data

Assessment of Existing Format

- 2D intensity images
  - With dynamic range of 0~255
  - Can be efficiently stored into TIFF, PNG, JPEG and JPEG 2000
  - JPEG or JPEG2000: most widely used, no need to investigate a new format
  - Proper compression rate: adjusted by users

Assessment of Existing Format

- 3D range images
  - 3D height dynamic range: at least 10-bit to 12-bit data; need of 16-bit
  - Existing 3D formats: mostly developed for storage of complex un-organized data (**do not meet our needs**)
  - Pavement surface: well organized "grid" data which can be stored and compressed using optimized raster graphics formats with high efficiency

Survey Results

- 15 Participated
  - 10 DOTs
  - 4 Vendors
  - 1 Academia
- 14 Responded
  - 11 DOTs
  - 3 Vendors

Survey Results

- Data collection technology: 2D (3), 3D (3), hybrid 2D & 3D (10)
- Preferred 2D image type: Gray 8 bits (11), Color 24 bits (3)
- 3D data dynamic range: 12 bit (2), 16 bits (9), unknown (5)
- 2D image compression: JPEG (12) & JPEG2000 (4)
- 3D image compression: JPEG (11) & JPEG2000 (2), XML (1), proprietary (2)

Task 3 Evaluate Data Items &Formats

- **Completed**
  - Identify and Select Best Practices of Image Data Collection
  - Evaluate Data Items Collected and Data Formats
  - Prepare and Submit Interim Report

Task 4 Develop Metadata & Standards

- Develop Data Format Requirements
- Develop File Structure and Data Format
- Evaluate and Incorporate Compression Algorithms for 2D/3D Image Data
- Develop Guidelines for the Development of Future Pavement Viewer Software

Task 4 Develop Metadata & Standards

- Develop Guidelines for Future Database Management
- Recommendation of Developing Web-Based Validation Software
- Draft Proposed Standards

All subtasks are completed

Guiding Principles

- Simplicity: self-contained
- Low barrier for adoption
- Encoding/decoding Speed
- Backward & forward compatibility
- Extensibility: new technologies

File Structure

Core Sections

File Header	2D Intensity Data	3D Range Data	Metadata

1. Backward compatibility - read & display a file written based on gen 1 definition
2. Forward compatibility - read & display newer format in the future

File Header

- Core Properties of 2D/3D Data
  - Reading 2D/3D data: file format version, image size, resolution, bit depth, compression algorithm, storage offset
  - Fast archiving and retrieving for database management

Metadata Section

- Metadata data formats
  - Rigid: fixed sized fields and records
  - Flexible: self-documenting structures with variable lengths and structure
  - Hybrid: with merits of both approaches, such as ASTM E2560-13

Data Section

- Blocks of binary data generated by compression algorithms
- Compression Algorithm Methods
  - Lossy: such as JPG, JPEG2000
  - Lossless: such as PNG
  - Hybrid: with the merits of both

3D Compression Methods

- Two criteria:
  - Capable to handle 16-bit depth data
  - Available for public access, free of patents
- Survey of compression methods
  - JPEG2000: offers both lossy and lossless compression for 16-bit data
  - JPEG XT: backward compatible with JPEG
  - JPEG XR: not been updated since 2006 (excluded)
  - 16-bit TIFF (GeoTIFF - same method as TIFF)
  - Proprietary compression method (OSU)

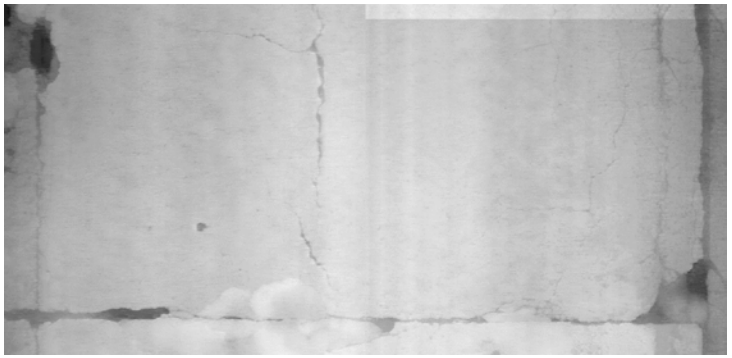
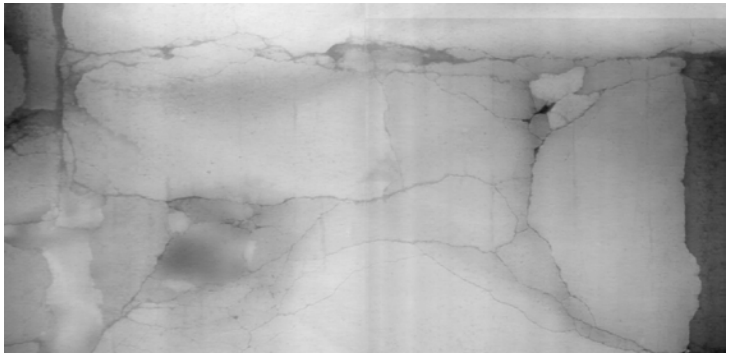
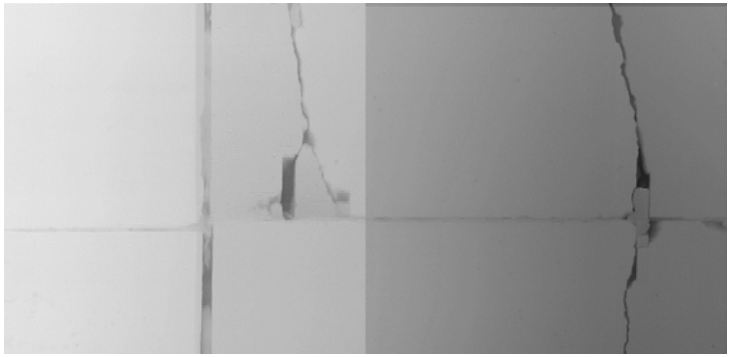
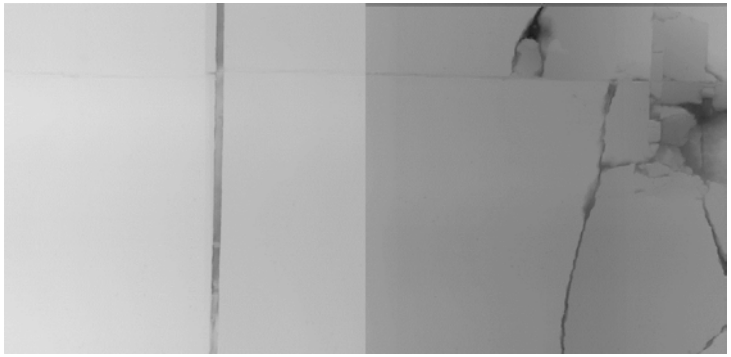
3D Compression Methods

- Peak Signal-to-Noise Ratio (PSNR)
  - The ratio of power between the maximum of signal & corrupting noise
  - For evaluation of compression algorithm
- Degree of compression (Compression Quality Factors – CQF)
  - Tradeoff btw storage size & image quality
  - JPEG & JPEG XT: adjustable
  - 16-bit TIFF & OSU method: not available
  - JPEG 2000: not available, but can be adjusted by using a pre-defined compression ratio

3D Compression Methods

- A critical need of the compression methods
  - Future Proof for Data Resolution, Definition, and Quality
  - Computational efficiency (speed) is a secondary consideration at this stage

3D Compression Methods

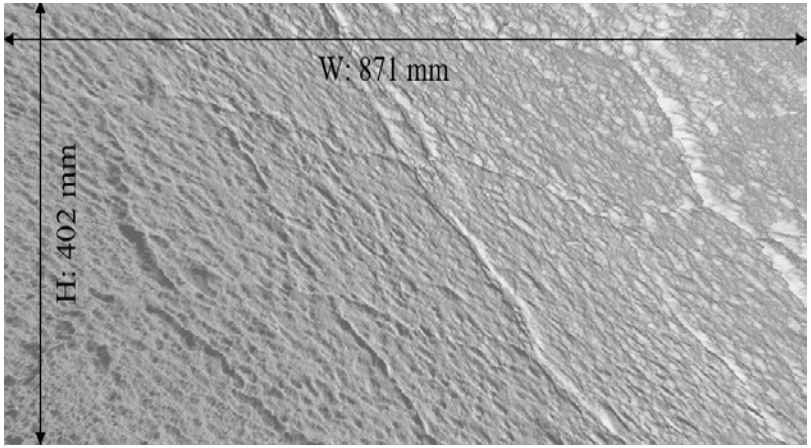
- Testing images: 3D 16-bit Dara
  - Asphalt – 2; Concrete - 2

3D Compression Methods

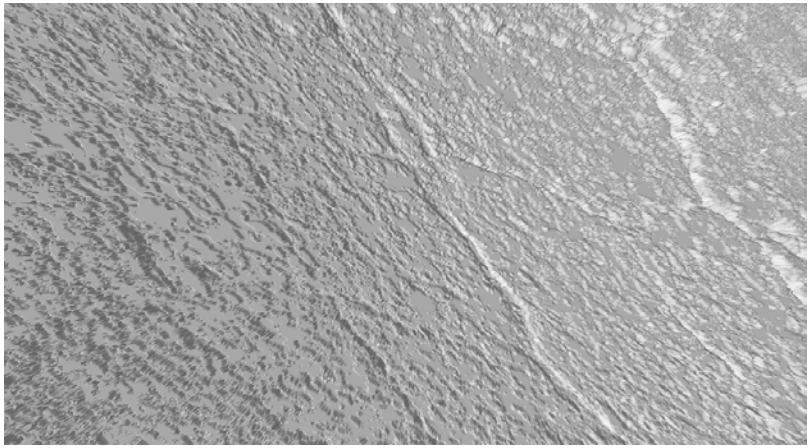
Methods	Time (ms)	Compression Ratio	PSNR
16-bit TIFF	271	5.6 : 1	Inf.
JPEG 2000	4668	32 : 1	67.3
JPEG XT	320	31 : 1	90.2
OSU Lossy	33	49 : 1	91.7
OSU Lossless	1854	14 : 1	Inf.

1. The time (ms): measured in a 2014 mid-range computer. OSU Lossy is optimized with multi-thread & GPU parallel algorithms; OSU Lossless is single-thread only with no parallel processing
2. Substantial efficiency improvement can be made on OSU Lossless.
3. Image length: about 2-meter or 7-ft

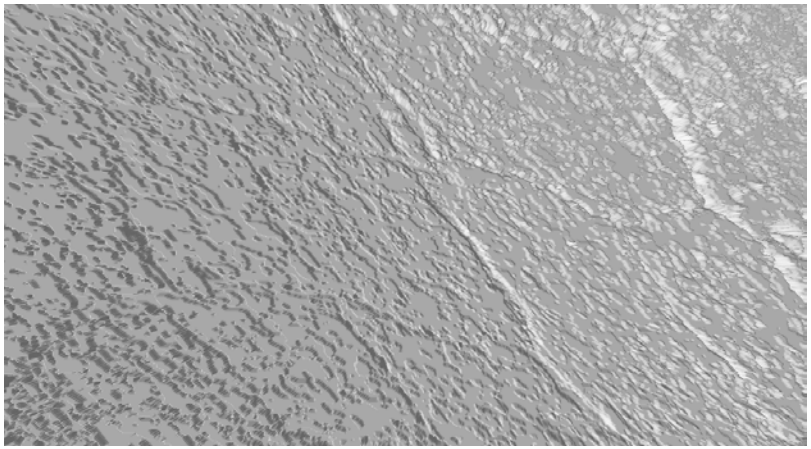
Visual Evaluation of Lossy Method



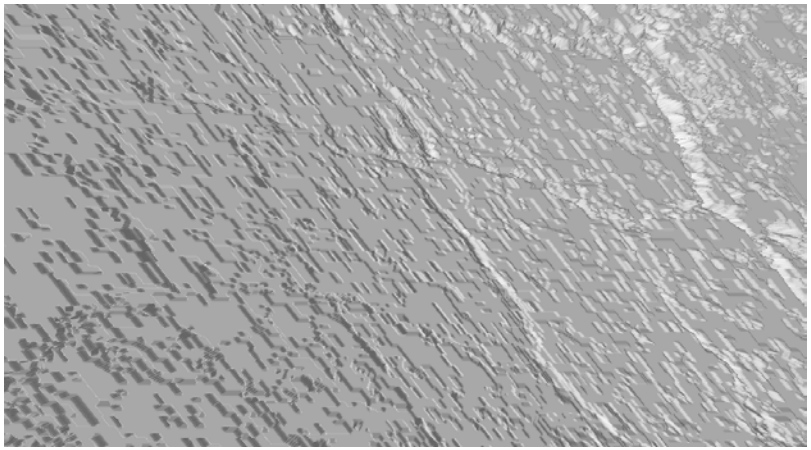
Original/Lossless Data



CQF: 100



CQF: 95



CQF: 85

Guidelines for Viewer Software

- Aid in the implementation of the new data format
- Two levels of design
  - Single File Viewer: display 2D/3D images in a single file
  - Route Viewer – display several to several 100 meters in length for a single-lane pavement

Recommendations

- Lossless OSU compression method
  - highly compressed & lossless operation on high-resolution 3D data
  - Current test: slow but high compression ratio
- Improvement of computation efficiency
- Development of a software viewer: compliance validation of the new data format with integrated compression algorithm

Thank You!

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