3D Point Cloud Compression using Conventional Image Compression for Efficient Data Transmission

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***Abstract*—Modern 3D laser scanners make it easy to collect large 3D point clouds. In this paper we present the use of conventional image based compression methods for 3D point clouds. We map the point cloud onto panorama images to encode the range, reflectance and color value for each point. An encoding method is presented to map the floating point measured ranges on to a three channel image. The image compression methods are used to compress the generated panorama images. We present the results of several lossless compression methods and the lossy JPEG on point cloud compression. Lossless compression methods are designed to retain the original data. On the other hand lossy compression methods sacrifice the details for higher compression ratio. This produces artefacts in the recovered point cloud data. We study the effects of these artefacts on encoded range data. A filtration process is presented for determination of range outliers from uncompressed point clouds.**

Keywords*—3D laser measurement systems, 3D point clouds, lossless compression, lossy compression, panorama images

I. Introduction

Light Detection And Ranging (LiDAR) systems are used to generate accurate and high resolution 3D point clouds. Sensors such as Microsoft Kinect, stereo cameras, 2D/3D laser scanners produce large amount of data. Advances in technology have widened the use of 3D data acquisition techniques. 3D point clouds are generated for many applications such as 3D environment modelling, surveying, archeology and specially for mobile robotics. Mobile robots are in turn used for variety of applications. One key application for mobile robots is their use in dangerous and hazardous environments. This includes exploration and digitisation of hazardous environments in search and rescue missions. Based on the application and human interaction with the robot these systems are either controlled remotely, semi-autonomous or functioning fully autonomously. For semi-autonomous or remote controlled systems it is necessary for the robot to communicate with a remote system and to transmit data to the operator. Operators require to see the robot environment to manipulate the platform. Therefore, the data acquired by sensors on the robot have to be transmitted fully or partially over a wireless network to the off-board system. Common wireless networks such as WiFi and HSDPA are relatively slow networks and have a limited bandwidth. Additionally, the maximum bandwidth of wireless network usually cannot be achieved, due to the distance between sender and receiver and environmental factors such as walls, objects and interference with other wireless networks. But vision sensors such as stereo cameras and 2D/3D laser measurement systems generate very large amount of data. The bottleneck in tele-operation of these systems is often the slow network capabilities. Besides the user interaction with the mobile robot, the use of an off-board system to increase the process power is advantages for fully autonomous robots. In the real world the transmission limitation prevents the full stream of data over the network. Other than data transmission the area of archiving 3D point clouds require a very large amount of storage. Modern 3D laser measurement systems are capable of very fast point measurements for example the rotational speed of Z+F IMAGER 5010C scanner is 3000 rpm and it is capable of measuring more than 1 million points per second [1]. The scans contain the range of each measurement and the reflected value of the measured surface. Many 3D laser measurement systems are capable of capturing the color of the environment in addition to the range and reflectance measurements. E.g., the Z+F IMAGER 5010C has an integrated High Dynamic Range (HDR) color camera [2]. The HDR camera captures the color information for each scan. The raw data from a 3D laser measurement or vision system is commonly stored in ASCII format. These large files are used for transmission and archiving of the point cloud. This rises the problem of data storage and how to minimize the amount of data with no or limited loss of information. High-end laser scanners have a large dynamic range, e.g., the Riegl VZ-400 has a range from 0.5 m to $\sim$400 m with an accuracy of a few millimeter.

In this paper we address the problem of efficient compression of acquired data from 3D laser measurement systems. The fundamental observation is that the captured data with such a 3D laser scanner can be presented in the form of a panorama image. Therefore, we exploit the use of compression methods in image processing for 3D point cloud compression.

II. State of the Art

The LiDAR data is typically stored in vendor specific binary files and for exchange between users the simple ASCII representation is preferred. In the ASCII representation each line contains the list of attributes of each measurement. This is flexible and easy to understand. However storing millions of LiDAR measurements in a textual format generates large files for which only inefficient parsing capabilities exist. The American Society of Photogrammetry and Remote Sensing (ASPRS) created a simple binary exchange format namely the LAS format [3]. Furthermore, LAZ a lossless compressor for LiDAR data stored in LAS format is presented in [4]. The LASzip compressor is a lossless, non-progressive, order-preserving compressor that provides random-access to the data. Mongus et al. [5] presents three step lossless method for compression of LIDAR LAS files. They apply a predictive coding, a variable-length coding and an arithmetic coding consequently. The key to their method is the use of three predictors for x, y and z coordinates and a separate predictor for scalar values, associated with each point. Several other approaches have been proposed in literature for compression of point clouds. Some approaches employ special data structures such as octree and k-d tree. A k-d tree approach presented by [6] and [7] uses a tree structure for recursively splitting and subdividing the point cloud. Elseberg et al. [8] present a method to encode one billion points in the cloud in an octree data structure on conventional hardware. Similarly [9] explore the compression of point cloud based on octrees. Peng at al. [10] and Huang at al. [11] use the octree structure for progressive encoding of point clouds. The octree structure provides a multi resolution spectral decomposition of the point cloud. This allows for encoding of point clouds of higher resolution from subsampled low resolution versions of point clouds. Progressive point cloud coding techniques are particularly important in scenarios with low bandwidth network or with high possibility of connection loss. It provides the receiving system with low resolution point cloud first and based on that generates the higher resolution point cloud. Schnabel et al. [12] and Peng at al. [13] use a prediction scheme to further improve the octree approach. Octree approaches are specially effective on large free space areas. Similar to this, Kammerl et al. [14] presents a novel compression approach which exploits spatial and temporal redundancy within the point cloud data stream. Their algorithm compresses the octree by expressing the differences of current point cloud with respect to previous one.

Point clouds can be encoded in panorama images. These images contain the range measurements. In addition to range the reflectance and color values are also encoded into same or separate images. Image based compression methods can be applied to these image. Savakis [15] presents a comparative study of many lossless compression algorithms (UNIX compress, GZIP, LZW, old lossless JPEG, JPEG-LS based on LOCO, CALIC, FELICS, S+P Transform, PNG and other non-grey-scale methods). Kaess et al. [16] focuses on real-time compression of laser data on board of a mobile robot platform. For compression purposes they presented the laser data as a grey scale depth image. They have considered UNIX compress, GZIP, BZIP2, PNG, JPEG-LS and wavelet transformations for compression. Krishnamurthy et al. [17] investigated the use of image compression algorithm on depth based images. They introduce two improvements. Region of interest coding where they identify regions with most crucial depth and reshaping the dynamic range of depth map. They achieved improvement over the standard JPEG2000. Prediction models for image transformation is used by Ghamisi et al. [18] to introduce low complex and efficient lossless compression method for LiDAR rasterised data. They have presented a novel real time algorithm for lossless compression of remote sensing data. They have presented a comparison of their method with other compression methods such as lossless JPEG and lossless version of JPEG 2000. Nenci et al. [19] have extended the compression of range data to video compression methods. Mobile robots require the ability to transmit stream of data to a base station or an operator. Transmission of raw sensor data over low bandwidth network is problematic. In [19] they present a method that exploits H.264 compression to reduce the size of the data stream from sensors such as the Kinect.

III. PANORAMA IMAGE GENERATION

Many methods have been proposed in literature to store the 3D point clouds such as octree, k-d tree and various binary formats, ASCII and even xml-based formats. However, due to the scanning process generated point clouds form 3D laser measurement systems can be mapped to panorama images. The measured environment can be imagined as points projected onto a sphere with the scanner positioned at the center of the sphere. Panorama generation is the process of mapping the spherical coordinates θ, φ, r of the measured points to the image coordinates x and y.

Mapping a spherical coordinate on to 2D coordinates is a renowned practice in the cartographic filed. Numerous methods have been developed over the years to map the earth. The equirectangular is the simplest projection that maps the longitude and latitude to horizontal and vertical coordinates. The Mercator projection is a more advanced method for mapping. It is related to equirectangular and cylindrical projection. However, it shows less pronounced distortion compared to aforementioned methods. The Mercator is a conformal projection, i.e., it preserves the angles. In recent years the Pannini projection has attracted researchers attention. It is a mathematical rule for constructing perspective image with a very large field of view. It corresponds to a rectilinear projection of a 3D cylindrical image. Detailed explanation of the several projections and different applications of them are available in our previous works [20] and [21]. Conic and azimuthal projections are also possible.

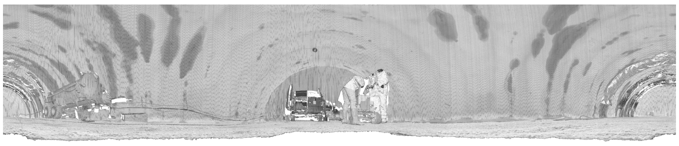
Equirectangular projection maps the longitude and latitude of each measurement to vertical and horizontal coordinates of the image. This projection supports 360-degrees horizontal and 180-degrees vertical field of view. 3D laser measurement systems utilise a horizontal motor and a vertical rotational mirror to acquire 360-degrees point clouds. The resolution of the captured point cloud is defined by angular differences between each measurement. The horizontal and vertical field of view and the resolution of the 3D laser measurement system dictates the panorama size. This satisfies one to one relation between each panorama pixel and each measurement. Therefore a full 360-degrees point cloud is mapped to one panorama image. Modern scanners provide in addition to range measurements reflectance and color values from measured environment. This data can be used to generate panorama images with color and reflectance values, cf. Fig. 1.

IV. POINT CLOUD COMPRESSION USING PANORAMAS

In this paper we operate on point clouds captured with terrestrial 3D laser measurement systems. We project each point cloud on to a panorama image with equirectangular projection (Fig. 1 (a) and (c)). This allows the use of conventional image compression methods to obtain a compressed point cloud. Compression algorithms can be categorised in lossless and lossy methods. In lossless methods all the information contained in the original data can be reconstructed from the compressed data. On the other hand lossy methods to a certain degree sacrifice the details in the compressed data for a significantly higher compression ratios. Lossless compression methods are preferred for point cloud compression. They preserve the original data therefore can be used for data archiving. The

(a) Color panorama image with equirectangular projection built from a point cloud captured by Z+F IMAGER 5010C from city center of Hannover, Germany.

(b) Color panorama image with the Mercator projection built from a point cloud captured by Z+F IMAGER 5010C from city center of Hannover, Germany.



(c) Reflectance panorama image with equirectangular projection built from a point cloud captured by Riegl VZ-400 from inside a tunnel.

(d) Reflectance panorama image with the Mercator projection built from a point cloud captured by Riegl VZ-400 from inside a tunnel.

Fig. 1. Panorama presentation of captured data with Z+F IMAGER 5010C and Riegl VZ-400. The Z+F IMAGER 5010C has a 360-degree horizontal field of view and 160-degree vertical field of view. The Riegl VZ-400 has a 360-degree horizontal field of view and 100-degree vertical field of view. The panorama image size is dictated by field of view of the measurement system. This causes vertically smaller panorama images for Riegl VZ-400.

higher compression ratio of lossy methods generates smaller point clouds. They can be used for visualisation and fast data transmission over the low band width networks.

A. Using Conventional Image Compression

Joint Photographic Experts Group (JPEG) standards are well known image compression methods. JPEG standard contains many methods for image compression. The most widely implemented method in JPEG is a lossy form of compression based on discrete cosine transform (DCT) [22]. The compression process starts by grouping the source image samples into 8×8 blocks. Their values are shifted to centred around zero. The DCT is applied to the shifted blocks. The DCT coefficients are uniformly quantised in conjunction with a quantisation table. Quantisation is the process of removing the high frequency data. This is the lossy part of DCT-based JPEG. The final step of compression is the entropy coding. This step achieves additional lossless compression by encoding the quantised DCT coefficients with Huffman coding [23].

The JPEG compression method is usually lossy. This means some of the original image information is lost and cannot be restored after decompression of the data. This data loss affects the image quality. However, for normal image applications small deformation of the data can be sacrificed for a higher compression ratios. In this paper we will present the effects of lossy compression on 3D point clouds. JPEG standard also presents less common lossless compression methods. JPEG 2000 is a compression method based on discrete wavelet transform (DWT), scalar quantisation, context modelling, arithmetic coding and post compression rate allocation [24]. JPEG2000 provides both lossless compression and lossy with higher rates of compression.

Portable Network Graphics (PNG) [25] is a patent free, W3C recommendation for coding still images. PNG is an extensible file format for the lossless, portable, well-compressed storage of raster images. A predictive scheme and entropy coding are the two steps of this compression method. The prediction is done on the nearest neighbours and there are five predictors in the specification. Entropy coding is done by non patented lossless data compression method known as Deflate algorithm [26]. This method compress the data using a combination of the LZ77 algorithm [27] and the Huffman coding. PNG is a lossless compression an supports grey scale, color and alpha channel.

Tagged Image File Format (TIFF) [28] is used for storing the images. It incorporates many options. A TIFF file can be a container to hold the raw data of the image ,i.e., the image data without compression. It also supports many compression methods. The most common and general purpose compression algorithm used with TIFF is the lossless Lampel-Ziv-Welch (LZW) [29] compression method. Similar to LZ77 and LZ78 [30], LZW is a dictionary based lossless compression method that works on generic data coding. Another common compression method supported by TIFF is the PackBit compression scheme. This is a simple and fast lossless compression that relies on run length encoding (RLE). This algorithm encodes the redundant information by storing the series of identical pixels with a control bit and the value of the compressed pixel.

We have utilised the aforementioned conventional image compression methods to compress the point clouds captured by a 3D laser measurement system. Separate panorama images are generated for range, color and reflectance data from the point cloud and subsequently compressed to minimize the required memory for each point cloud. This improves the data archiving and data transmission over low bandwidth networks.

B. Range Encoding and Point Cloud Compression

Our approach starts with encoding range, color and reflectance values into separate panorama images. It is a common practice for 3D laser measurement systems to present the reflectance data with 8 bit grey value. Color information is often presented with three 8 bit red, green and blue values. Range information however is a floating point value to present the distance between the measured environment and 3D laser measurement system in meters. A greyscale image and an RGB image are generated to present the reflectance and color data from the captured point cloud. A problem of conventional image compression methods for range data is the number of bits per pixel that compression method supports. Most compression methods support only 8 bits per pixel and this value cannot be changed easily. A single precision floating point has a width of 32 bits. In order to encode the range information onto an image for compression, we multiply range by scale factor of 10^4 and convert the float to integer. This generates integer range values with 0.1 millimetre accuracy.

There is a common missconception that floating point representation provides more precision than integer. Storing a value in floating point representation means that the precision of the value varies depending on the number of the value. Numbers closer to zero have more precision. On the other hand 0.1 millimetre range accuracy is higher than the range accuracy of most 3D measurement systems. The highest 24 bit integer value is $2^{24} = 16777216$ and with 0.1 millimetre accuracy we can encode ranges up to 1676 meters in 24 bits of data. This can be used to map the range information with 0.1 millimetre accuracy on an RGB image. The 24 bit range is divided bitwise into three 8 bit values to fill the red, green and blue of the image, cf. Fig. 2. The RGB color model is an abstract mathematical model describing a way to present a color in tuples of numbers. A color space is the interpretation of the components of a color model. Adding a mapping function between color model and a reference color space creates a footprint or gamut which defines the color space for a specific color model. Our proposed range to color encoding method has no connection to any globally known system of color interpretation and it is capable of mapping 2^{24} ranges to 2^{24} colors. Several other color mapping methods exist, such as jet, hot and rainbow spectrum colors, however these methods contain only part of the RGB color space, e.g., a color map with 32000 different colors maps range values from a point cloud with maximum 400 meter range with only 1.25 centimetre accuracy. This is much less than the accuracy of 3D laser measurement unit. To have a high accuracy range to color map all 2^{24} colors is used. Utilising color maps that are part of the RGB color model result in loss of data. Therefore, these methods are not suitable for our range encoding.

In our proposed range encoding method the colors are sorted based on values of the blue, green and red colors. Therefore the value of blue channel is mostly close to zero and it only increases approximately every 6.5 meters. On a scan with maximum range of 200 meters the blue channel increases to 30. Therefore the blue color is not prominent in the image and shades of green and red are mapped to every 6.5 meters (See Fig. 2). A more intuitive representation of range is a smooth transition between colors to present the increase in range. To produce such a color map we mapped the sorted RGB colors based on blue, green and red to HSL (hue-saturation-lightness) color model and sort the colors based on hue, saturation and lightness. Figure 3 represents 2^{24} RGB colors sorted based on HSL color model. This maps the range 0 to the top left corner and 16777216 to the bottom right of Fig. 3. This color map is used for generation of the three channel image with encoded range value of a scan (see Fig. 4). The color transitions from darker blue to lighter blue. The range of used colors are dependent on the maximum range of the scan. Therefore scans with longer range include other colors from the Fig. 3.

A 3D point cloud is compressed by use of conventional image compression methods into three channel range image, reflectance image and color image.This data can be archived or transferred over network efficiently. To recover the point cloud, images containing range, color and reflectance are decompressed and the range information is restored from three

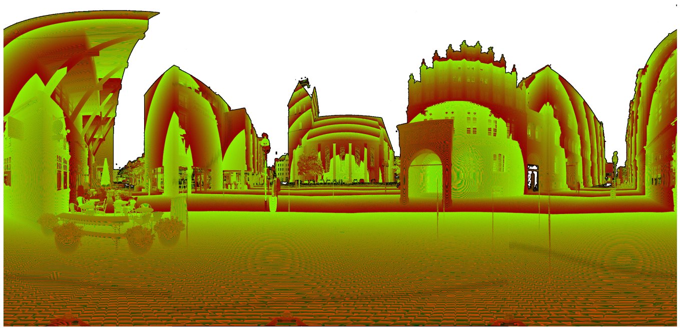


Fig. 2. Range encoding onto three channel panorama image.

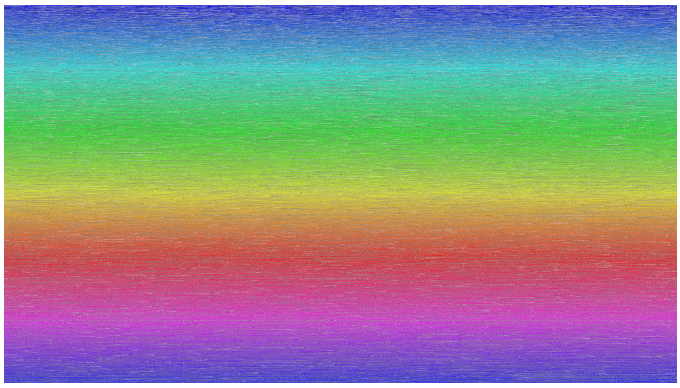


Fig. 3. All RGB colors with depth of 8 bit sorted based on HSL color model.

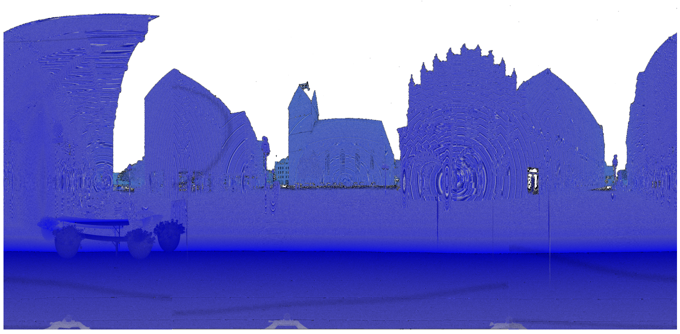


Fig. 4. Range encoding onto three channel panorama image with HSL color sorting.

channel image.

JPEG compression method for color images is tailored for human eye to reduce the detachable artefacts in compressed image. Human eye is more sensitive to changes in intensity than the color hue. Therefore, JPEG compression method mostly converts the RGB color scheme to YCbCr and it uses higher compression ratio on chrominance than the luminance of the image. This provides higher compression and the compression artefacts are less detectable. In this paper to avoid different compression ratios for JPEG method, in addition to using three channel image to compress the range we also used three grey scale images. The JPEG method on grey scale images uses the same compression ratio as the luminance on color images. Due to lossy aspect of JPEG compression, the recovered range from compressed image does not mach the original range for each measurement. We used the three grey scale image for compression to reduce this difference.

V. Examples and Results

The experiments are designed to present the potential of image compression methods for point cloud compression. Furthermore, they present the effects of lossy compression on point clouds. First we compare lossless compression methods. Second we evaluate the impacts of lossy JPEG compression with different quality settings. Third we present a comparison of two presented range encoding methods based on RGB and HSL color maps.

To compare all the aforementioned compression methods, two data sets have been used. First data set is a single scan from Riegl VZ-400 3D laser measurement system from inside a tunnel (See Fig. 5 (a)). This 3D laser measurement system only provides the range and reflectance information of the environment. Second data set is a single scan from Z+F IMAGER 5010C from Hannover city center in Germany (See Fig. 5 (b)). In addition to range and reflectance this 3D laser measurement system provides color information for measured points. For compression methods we rely on libpng, libjpeg, libtiff and libjasper. Comparison of lossless image compression methods are presented in Table I. In addition to lossless image compression methods Table I includes the standard ASCII and LAS format. Two other compression methods are the lossless compression of LAS format namely LAZ and the representation of point cloud in octree structure based on [8].

The results show PNG to have the highest compression ratio. The uncompressed TIFF also has lower file size than LAS and octree method. The use of pixel coordinates as longitude and latitude of 3D points and the encoding of the range from a floating point into to 24 bit three channel pixel provides lower file sizes. The presented file sizes for image based compression methods are the combination of separate three channel range, grey scale reflectance and RGB color images. Table II provides more detailed comparison of compression methods for Hannover data set.

The main advantage of lossless compression methods is to provide a compression with out loss of data. The introduced error in lossy method is inevitable. JPEG compression is designed to perform higher compression on chrominance of the image than the luminance. The quality setting of JPEG compression is a measurement unit to produce images with

TABLE I. Comparison of different compression methods for the two data sets. Data set 1 was captured from inside a tunnel with Riegl VZ-400 3D laser measurement system. This data set contains range and reflectance values. Data set 2 was captured from city center of Hannover, Germany with Z+F IMAGER 5010C 3D laser measurement system. This data set contains range, reflectance and color values. The size of image based compression methods is the combination of all generate images.

Compression Method	Data Set 1	Data Set 2
ASCII	681.5 MB	1.44 GB
LAS	440.5 MB	1.16 GB
LAZ	62.3 MB	170.9 MB
OCT	352.5 MB	889.5 MB
PNG	35.8 MB	142.2 MB
JPEG 2000	51.3 MB	149.2 MB
TIFF with no compression	90 MB	350 MB
TIFF with LZW	47 MB	144.8 MB
TIFF with PackBits	62.4 MB	247 MB

TABLE II. File sizes of compressed three channel range, grey scale reflectance and RGB color images of Hannover data set.

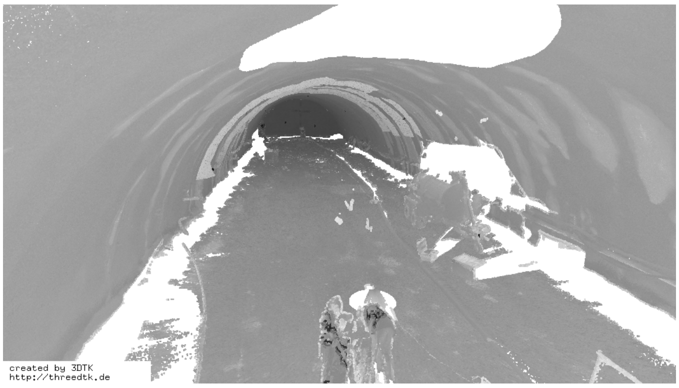
Compression Method	Three Channel Range	Grey Scale Reflectance	RGB Color
PNG	29.2 MB	24.4 MB	88.6 MB
JPEG 2000	55.3 MB	37.7 MB	61.2 MB
TIFF with no compression	150 MB	50 MB	150 MB
TIFF with LZW	27.5 MB	29 MB	88.3 MB
TIFF with PackBits	103.5 MB	36 MB	107.5 MB

different compression ratio. Higher quality setting generates less compressed images. We have an additional three grey scale images for encoding the range to keep same level of compression on all range channels. Fig. 6 presents a recovered point cloud after JPEG compression with quality 100 for both three channel range encoding and three grey scale image range encoding and the results from lossy JPEG compression with different quality settings are presented in Table III.

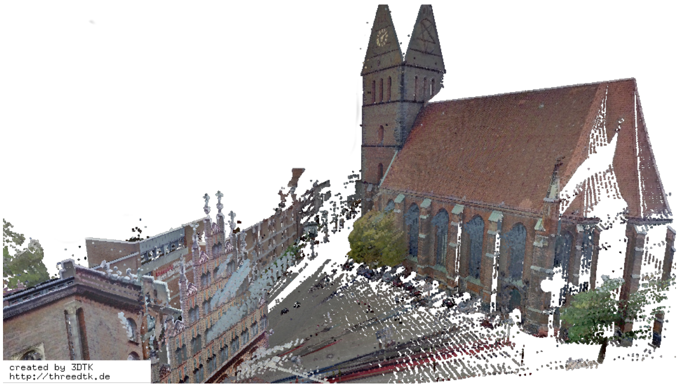
The lossy compression as expected has higher rates of compression. The introduced error based on the lossy method results in a very imprecise recovered point cloud. Using three separate grey scale to encode the range improves the result. However, the recovered point cloud still contain many outliers. Using three grey scale images for range encoding improves the compression ratio of lossless methods. In contrast lossy JPEG compression ratio decreases as a result of same compression on all three channels of range as a substitute for higher compression on chrominance than luminance.

TABLE III. Comparison of three channel and three grey scale range encoding for lossy JPEG with few quality settings and lossless compression methods. Tunnel data set is used for creation of this table.

Compression Method	Three Channel Range	Three Grey Scale Range
JPEG 100	26.2 MB	38.3 MB
JPEG 95	15.1 MB	23.8 MB
JPEG 50	4.4 MB	9.1 MB
PNG	24.4 MB	20.1 MB
JPEG 2000	37.6 MB	25.4 MB
TIFF with no compression	67.5 MB	67.5 MB
TIFF with LZW	31.4 MB	27.9 MB
TIFF with PackBits	46.6 MB	35.5 MB

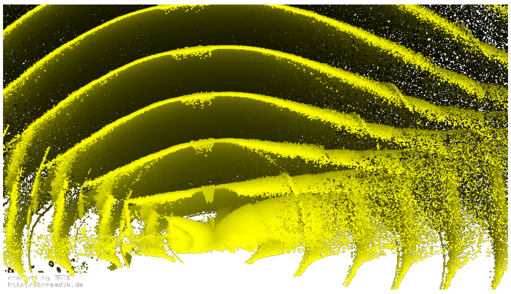


(a) Rendering of the point cloud captured by the Riegl VZ-400 (viewed from inside the tunnel).

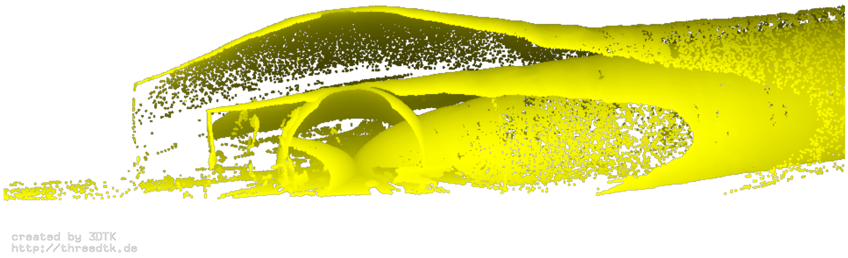


(b) Rendering of the point cloud captured by the Z+F IMAGER 5010C.

Fig. 5. 3D views of the point clouds sued in the experiments. The Riegl VZ-400 provides range and reflectance measurements for each 3D point. The Z+F IMAGER 5010C provides range, reflectance and color for each measured point.

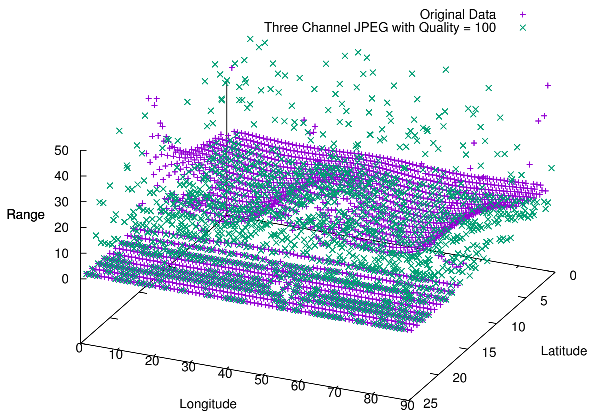


(a) Three channel image range encoding method.

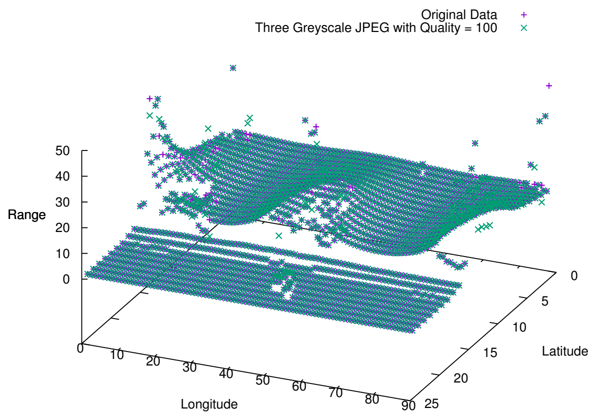


(b) Three grey scale images range encoding method.

Fig. 6. Recovered point cloud from encoded range in JPEG panorama image with compression quality setting of 100.



(a) Original data and three channel image range encoding method.



(b) Original data and three grey scale ranges encoding method.

Fig. 7. Comparison of the original range value with recovered range value from JPEG compression based on three channel image range encoding and three grey scale images range encoding. The JPEG quality of 100 is used for this comparison. Image coordinates x and y are mapped back to longitude and latitude and the range value is presented as elevation for each plotted pixel. This shows the improvement of using three grey scale images for range encoding over three channel range encoding for recovered point clouds from JPEG compression.

Fig. 7 presents the difference of recovered range values from JPEG compression with original range values. The presented result is a section of a larger panorama image. The range value is mapped as elevation for each image pixel. This shows the reduction of JPEG compression artefacts with use of three grey scale images for range encoding. Lower quality JPEG is used for higher compression however, this results in higher amount of artefacts in comparison to Fig. 7(b).

We implemented a filtration process for the decompressed point cloud from JPEG compression to remove the artefacts. To determine the range outliers for each image pixel the eight surrounding ranges are selected. The lower and upper quartile of selected ranges are calculated. The interquartile range is calculated to determine the boundaries for outlier selection. A scale factor is multiplied by the interquartile to define the tolerance of the filtration method for outlier selection. The

Algorithm 1 Filtration algorithm used to remove the outliers of recovered point cloud from JPEG compression method.

Require: $image$ {The JPEG compressed panorama image of a 3D point cloud}
Require: $T \geq 0$ {The scale factor to determine the tolerance of the filtration process}

```
for x = 0 to image.width do
  for y = 0 to image.height do
    p ← image[x][y]
    n ←getNeighboursOfPixel(p)
    sortByRange(n)
    q1 ← getLowerQuartile(n)
    q2 ← getUpperQuartile(n)
    interquartile ← (q2 − q1) ∗ T
    minBoundarie ← q1 − interquartile
    maxBoundarie ← q2 + interquartile
    if p.range ≥ minBoundarie and p.range ≤ maxBoundarie then
      Use this pixel for recovered point cloud
    else
      This pixel is considered as outlier and removed from recovered point cloud
    end if
  end for
end for
```

boundaries are calculated by adding the scaled interquartile to upper quartile and subtracting from lower quartile. Range values outside these boundaries are considered to be outliers and therefore removed from the recovered point cloud. This algorithm is described in Algorithm 1. The recovered point cloud from JPEG compression after the filtration process is presented in Fig. 8.

Range values from point clouds are encoded into 24 bit integer and divided in three 8 bit channels to be presented as color. We have used this color values to map the range onto a three channel RGB image as well as three grey scale images. We have presented two range encoding methods in this paper. First method encodes range to RGB colors sorted based on blue, green and red color values. Second method encodes the range to RGB colors sorted based on HSL color model. Table IV and V present a comparison between these range encoding methods. Utilising HSL to sort the RGB colors generates panorama images with smooth transition between colors to present the increase of range in the measured environment. However, smooth transition in color results in RGB values to be close to each other and not necessarily a small value. On the other hand the encoding method with color map sorted based on blue, green and red has small values mostly for blue channel based on maximum range of the point cloud. Furthermore, the green and red channels have repetitive behaviour. This results in higher compression of data, specifically on blue channel.

TABLE IV. COMPARISON OF COLOR MAPPING METHOD FOR RANGE ENCODING. COLOR MAPS REPRESENT ALL THE COLORS IN THE RGB COLOR MODEL WITH 8 BIT DEPTH FOR EACH COLOR CHANNEL. COLOR MAP 1 SORTS THE COLORS BASED ON BLUE, GREEN AND RED COLORS. COLOR MAP 2 SORTS THE COLORS BASED ON HSL COLOR MODEL. THE COMPARISON PRESENTS THE DIFFERENCE BETWEEN THREE CHANNEL RANGE ENCODING METHOD GENERATED FROM TUNNEL DATA SET.

Compression Method	Color Map 1	Color Map 2
JPEG 100	26.2 MB	27.9 MB
PNG	24.4 MB	42.2 MB
JPEG 2000	37.6 MB	39.9 MB
TIFF with no compression	67.5 MB	67.5 MB
TIFF with LZW	31.4 MB	48.9 MB
TIFF with PackBits	46.6 MB	46.8 MB

TABLE V. COMPARISON OF COLOR MAPPING METHOD FOR RANGE ENCODING. COLOR MAPS REPRESENT ALL THE COLORS IN THE RGB COLOR MODEL WITH 8 BIT DEPTH FOR EACH COLOR CHANNEL. COLOR MAP 1 SORTS THE COLORS BASED ON BLUE, GREEN AND RED COLORS. COLOR MAP 2 SORTS THE COLORS BASED ON HSL COLOR MODEL. THE COMPARISON PRESENTS THE DIFFERENCE BETWEEN THREE GREY SCALE RANGE ENCODING METHOD GENERATED FROM TUNNEL DATA SET.

Compression Method	Color Map 1	Color Map 2
JPEG 100	38.3 MB	66.8 MB
PNG	20.1 MB	45.3 MB
JPEG 2000	25.4 MB	47.5 MB
TIFF with no compression	67.5 MB	67.5 MB
TIFF with LZW	27.9 MB	62.3 MB
TIFF with PackBits	35.5 MB	54.3 MB

VI. CONCLUSION

This paper compared several image compression methods in terms of compression of generated point clouds from 3D laser measurement systems. 3D point clouds are mapped on to panorama images. Range, reflectance and color data from point clouds are mapped onto separate panorama images. Range encoding method is presented to encode the measured ranges from floating points on to 24 bit three channel image. This process is required for use of image compression methods. Most image compression methods work with 8 bit grey scale or 24 bit three channel color images. Furthermore, we introduce a three grey scale images range encoding for JPEG compression to avoid the difference compression ratio on chrominance and luminance of color images. Comparison of several lossless image compression methods and the lossy JPEG is presented. Our experimental evaluation shows high compression ratio with conventional image compression methods for point clouds. These methods outperform the industry standard LAZ compression. The usage of PNG compression is recommended for such application, resulting in a lossless compression with the highest compression ratio. If errors can be accepted, lossy JPEG can be used. We have presented a filtration method to reduce the generated JPEG artefacts. This only woks for JPEG with high quality setting. Future work will concentrate on improvements on filtration method for possible use of JPEG with lower quality settings.

ACKNOWLEDGMENT

The authors would like to thank Zoller + Fröhlich GmbH for providing the Hannover dataset and ANGERMEIER INGENIEURE GmbH letting us acquire the tunnel data during construction.

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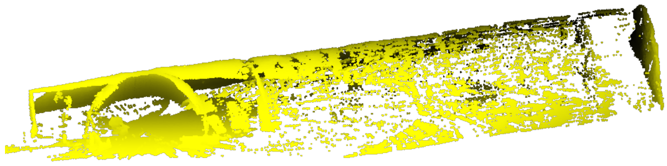
(a) Recovered point cloud from three grey scale images range encoding method for JPEG images with quality setting of 100. Presented data is the point cloud after filtration of range outliers based on our filtration method.



(b) Recovered point cloud from three grey scale images range encoding for JPEG images with quality setting of 95. Presented data is the point cloud after filtration of range outliers based on our filtration method. More aggressive filtration boundaries are used for this quality setting.

Fig. 8. Filtration performance on recovered point clouds from JPEG compression. The three grey scale method is used for range encoding with quality settings of 100 and 95. This presents the comparison of recovered point cloud with our filtration process. Despite point removal process the main structure is visible and understandable by human eye.

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