EPITA–École Pour l'Informatique et les Techniques Avancées
CSI–Calcul Scientifique et Image
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Various contributions to *ContextCapture*^{TM} : Scan Finder, Point Cloud Visibility and Point Cloud Compression

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Abstract

Text of the Abstract.

Acknowledgements

I would like to express (whatever feelings I have) to:

- My supervisor
- My second supervisor
- Other researchers
- My family and friends

Dedication

Dedication here.

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Chapter 1

Introduction

The need of 3D realistic models is increasingly present in several fields such as architecture, digital simulation or civil and structural engineering. One way to obtain a 3D model might be to build it by hand using specialized modeling softwares. In this case, the realistic aspect of the model could be doubtful. A more reliable way is to use *photogrammetry* or *surface reconstruction* or both at the same time. *ContextCapture*$^{\boldsymbol{TM}}$ is a reality modeling software that can produce highly detailed 3D models. It creates models of all types or scales from simple photographs of a scene to point clouds or both of them thanks to its hybrid processing. The usage of point clouds gained wide popularity because of the emergence of devices such as optical laser-based range scanners, structured light scanners, LiDAR scanners, Microsoft Kinect, etc. It is only in the past two years that *ContextCapture*$^{\boldsymbol{TM}}$ has started to support point clouds.

The general problem being solved by *surface reconstruction* is: given a point cloud P assuming to lie near an unknown shape S, construct a digital representation D approximating S. A critical step during the construction of D is usually the estimation and orientation of the normal of each point $p \in P$. In order to orient normals and reconstruct point clouds acquired from static[1] LiDAR scanners, possibly multi-scan[2], *ContextCapture*$^{\boldsymbol{TM}}$ needs to know the position of each scanner in the scene, on the one hand, and the attribution of each point to a scanner on the other. The scanners locations information are not always present in the metadata of some file formats, for instance LAS file format does not even provide it. Detecting the positions of multiple scanners exclusively from a point cloud is a subject neither tackled by academics nor the industry. The scanner position information is lost

[1] As opposed to mobile LiDAR scanners.
[2] Point cloud made of several laser scans.

only due to an export with no metadata. Thus, academic research has not identified this subject as interesting. It's only recently that scanner position information is relevant, for a few applications like *ContextCapture*^{TM} . The industry did not need an algorithm to retrieve the scanner position up to now and this is the main contribution presented in this internship report: a method able to detect automatically multiple scanners in a single point cloud without prior knowledge of the scene.

Knowing scanners position is one thing, orient normals is another. To do so, *ContextCapture*^{TM} needs to know for each point which scanner sees it best, there is no need to know exactly which scanner generated it. This enters into the realm of visibility of point clouds. One way to retrieve visibility of point clouds is to reconstruct the surface and use the underlying mesh to compute visibility. But to reconstruct the surface we need to orient the normals; a chicken-and-egg problem. In *Direct visibility of point sets* [KTB07], an elegant algorithm that computes visibility without reconstructing the surface is introduced: the Hidden Point Removal (HPR) operator. But this operator is not robust to noise which happens quite often in LiDAR point clouds. Some improvements have been proposed in [MTSM10] but are not good enough to handle LiDAR point clouds noise. Actually, both papers show results obtained on point clouds describing small closed surfaces such as the statue of David [dav] or the Stanford bunny [bun]. Moreover, our purpose here is not to find which points are visible from a precise viewpoint. Different scanners can see the same points and we want to know for each point which scanner best sees it in order to have an accurate normal orientation. We introduce in this internship report a custom point cloud visibility method that serves our purpose and works well with LiDAR point clouds, regardless of the sampling density.

Finally, the last subject covered during this internship is point cloud compression. Reconstructing a surface requires effective machines. The more the scene to reconstruct is bigger, the more the reconstruction can last longer. *ContextCapture*^{TM} provides a cloud service which gives the opportunity for people not having any clusters or high-performance machine to do the job. The problem is that, point clouds can be very huge, up to one hundred (100) gibabyte and more. And if something happens while uploading, the upload restarts from scratch. Being able to reduce the point cloud size and/or cutting it into pieces before uploading it is an interesting point for *ContextCapture*^{TM} cloud services. Point cloud compression can be adressed in two ways: geometric compression [GKIS05, SK06] or pure arithmetic compression regardless of the kind of file being compressed. We present... FIXME ...

This report is organised as follows. Chapter 2 present Bentley Systems, Acute3D, *ContextCapture*^{TM}

and how the achieved work is positioned in the company's business line. After introducing in Chapter 3 some useful definitions for a better understanding of the report, we describe the achieved work of Scan Finder, Point Cloud Visibility and Point Cloud Compression respectively in Chapter 4, Chapter 5 and Chapter 6. Note that in each chapter, we recall the context, the issue addressed and the expected result before going into details. Finally Chapter 7 summarizes all the work, evaluates my contributions to *ContextCapture*$^{\boldsymbol{TM}}$ and assess what this experience has brought to me.

Chapter 2

The company

This chapter shed more light on *ContextCapture*^{TM} , the software I contributed to during these six (6) months internship as well as Bentley Systems, the company. Actually I worked for Acute3D which had been acquired by Bentley Systems [acu] on February 10, 2015.

2.1 Bentley Systems

Bentley Systems is an American-based software development company founded by Keith A. Bentley and Barry J. Bentley in 1984.

For a bit of history[1], they introduced the commercial version of PseudoStation in 1985, which allowed users of Intergraph's VAX systems to use low-cost graphics terminals to view and modify the designs on their Intergraph IGDS (Interactive Graphics Design System) installations. Their first product was shown to potential users who were polled as to what they would be willing to pay for it. They averaged the answers, arriving at a price of $7,943. A DOS-based version of MicroStation was introduced in 1986. Later the two other brothers joined them in the business. Today, Bentley Systems is considered to have four (4) founders: Greg Bentley (CEO), Keith A. Bentley (EVP, CTO), Barry J. Bentley, Ph.D. (EVP) and Raymond B. Bentley (EVP).

At its core, Bentley Systems is a software development company that supports the professional needs of those responsible for creating and managing the world's infrastructure, including roadways, bridges, airports, skyscrapers, industrial and power plants as well as utility networks. Bentley delivers solutions

[1] Derived from [ben]

for the entire lifecycle of the infrastructure asset, tailored to the needs of the various professions – the engineers, architects, planners, contractors, fabricators, IT managers, operators and maintenance engineers – who will work on and work with that asset over its lifetime. Comprised of integrated applications and services built on an open platform, each solution is designed to ensure that information flows between workflow processes and project team members to enable interoperability and collaboration.

Bentley's commitment to their user community extends beyond delivering the most complete and integrated software – it pairs their products with exceptional service and support. Access to technical support teams 24/7, a global professional services organization and continuous learning opportunities through product training, online seminars and academic programs define their commitment to current and future generations of infrastructure professionals.

With their broad product range, strong global presence, and pronounced emphasis on their commitment to their neighbors, Bentley is much more than a software company – they are engaged functioning members of the global community. Their successes are determined by the skills, dedication, and involvement of extraordinary Bentley colleagues around the world.

Bentley has more than 3,500 colleagues in over 50 countries, and is on track to surpass an annual revenue run rate of $700 million. Since 2012, Bentley has invested more than $1 billion in research, development, and acquisitions.

2.2 Acute3D

Acquired by Bentley Systems in February 2015, Acute3D is now developing *ContextCapture*^{TM} , as part of Bentley Systems' Reality Modeling solutions.

Acute3D is a technological software company created in January 2011 by Jean-Philippe Pons and Renaud Keriven, by leveraging on 25 man-years of research at two major European research institutes, École des Ponts ParisTech and Centre Scientifique et Technique du Bâtiment. It won the French "most innovative startup" Awards. In 2011, Acute3D signed an industrial partnership with Autodesk, while keeping to advance its R&D work on city-scale 3D reconstruction. In 2012, Acute3D signed industrial partnerships with other industry leaders, including Skyline Software Systems and InterAtlas. In parallel, it started to commercialize its own Smart3DCapture® (now replaced by *ContextCapture*^{TM})

standalone software solution, optimized for highly detailed and large-scale automatic 3D reconstruction from photographs. In 2015, Acute3D is acquired by Bentley Systems, and becomes part of their end-to-end Reality Modeling solutions.

2.3 *ContextCapture^{TM}*

With *ContextCapture^{TM}* , you can quickly produce even the most challenging 3D models of existing conditions for infrastructure projects of all types. Without the need for expensive, specialized equipment, you can quickly create and use these highly detailed, 3D reality meshes to provide precise real-world context for design, construction, and operations decisions for use throughout the lifecycle of a project.

Hybrid processing in ContextCapture enables the creation of engineering-ready reality meshes that incorporate the best of both worlds – the versatility and convenience of high-resolution photography supplemented, where needed, by additional accuracy of point clouds from laser scanning.

Develop precise reality meshes affordably with less investment of time and resources in specialized acquisition devices and associated training. You can easily produce 3D models using up to 300 gigapixels of photos taken with an ordinary camera and/or 500 million points from a laser scanner, resulting in fine details, sharp edges, and geometric accuracy.

Extend your capabilities to extract value from reality modeling data with ContextCapture Editor, a 3D CAD module for editing and analyzing reality data, included with ContextCapture. ContextCapture Editor enables fast and easy manipulation of meshes of any scale as well as the generation of cross sections, extraction of ground and breaklines, and production of orthophotos, 3D PDFs, and iModels. You can integrate your meshes with GIS and engineering data to enable the intuitive search, navigation, visualization, and animation of that information within the visual context of the mesh to quickly and efficiently support the design process.

Chapter 3

Basic Concepts

This chapter introduces the necessary concepts and definitions for a better understanding of the report.

3.1 Point Cloud

Definition of point and its fields. Definition of point cloud.

3.2 Geometric operations

3.2.1 Translation

3.2.2 Rotation

3.2.3 Projection ??

3.3 Traditionnal algorithms

3.3.1 PCA

3.3.2 Least Square Solving

Linear

Non-linear

Talk about Ceres solver?

3.3.3 RANSAC

Text of the Background.

Chapter 4

Scan Finder

4.1 Specifications

4.1.1 Problem being addressed

4.1.2 Objective

4.1.3 Scope

4.2 Related Work

4.3 The faulty grid-pattern method

4.3.1 Overview

4.3.2 Grid-pattern matching

4.3.3 Equation to solve

4.3.4 Results and discussions

4.4 The working elliptic method

4.4.1 Overview

4.4.2 Clustering high-density area

Chapter 5

Point Cloud Visibility

5.1 Specifications

5.1.1 Problem being addressed

5.1.2 Objective

5.1.3 Scope

5.2 Related work

5.3 Direct Visibility of Point Sets

5.3.1 Overview

5.3.2 Implementation

5.3.3 Results and discussions

5.4 Visibility of Noisy Point Cloud Data

5.4.1 Overview

5.4.2 Implementation

5.4.3 Results and discussions

Chapter 6

Point Cloud Compression

6.1 Specifications

6.1.1 Problem being addressed

6.1.2 Objective

6.1.3 Scope

6.2 Related work

6.3 A custom arithmetic approach

6.3.1 Overview

6.3.2 Implementation

6.3.3 Comparison with Brotli, 7Z and Zip

6.4 Integration

Chapter 7

Conclusion

7.1 Summary of Internship Achievements

Summary.

7.2 Applications

Applications.

7.3 Future Work

Future Work.

Bibliography

[acu] Bentley acquires Acute3D to extend Reality Modeling portfolio. `http://gfxspeak.com/2015/02/10/acquires-modeling-portfolio/`. Accessed: 2018-07-05.

[ben] Bentley systems by wikipedia. `https://en.wikipedia.org/wiki/Bentley_Systems#History`. Accessed: 2018-07-06.

[bun] Stanford bunny. `https://en.wikipedia.org/wiki/Stanford_bunny`. Accessed: 2018-07-05.

[dav] David Michelangelo. `https://en.wikipedia.org/wiki/David_(Michelangelo)`. Accessed: 2018-07-05.

[GKIS05] Stefan Gumhold, Zachi Kami, Martin Isenburg, and Hans-Peter Seidel. Predictive point-cloud compression. In *ACM SIGGRAPH 2005 Sketches*, page 137. ACM, 2005.

[KTB07] Sagi Katz, Ayellet Tal, and Ronen Basri. Direct visibility of point sets. In *ACM Transactions on Graphics (TOG)*, volume 26, page 24. ACM, 2007.

[MTSM10] Ravish Mehra, Pushkar Tripathi, Alla Sheffer, and Niloy J Mitra. Visibility of noisy point cloud data. *Computers & Graphics*, 34(3):219–230, 2010.

[SK06] Ruwen Schnabel and Reinhard Klein. Octree-based point-cloud compression. *Spbg*, 6:111–120, 2006.