HAL
open science

COMPARATIVE ANALYSIS BASED ON SIMULATION FOR THE DESIGN OF LASER TERRESTRIAL MOBILE MAPPING SYSTEMS

Hyun-Jae Yoo, Francois Goulette, J Senpauroca, G Lepère

To cite this version:

Hyun-Jae Yoo, Francois Goulette, J Senpauroca, G Lepère. COMPARATIVE ANALYSIS BASED ON SIMULATION FOR THE DESIGN OF LASER TERRESTRIAL MOBILE MAPPING SYSTEMS. Int. Symposium on Mobile Mapping Technology, 2009, Presidente Prudente, São Paulo, Brazil. hal-01259671

HAL Id: hal-01259671

https://hal.science/hal-01259671v1

Submitted on 21 Jan 2016

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

COMPARATIVE ANALYSIS BASED ON SIMULATION FOR THE DESIGN OF LASER TERRESTRIAL MOBILE MAPPING SYSTEMS

H. J. Yoo [a, *], F. Goulette [a], J. Senpauroca [a], G. Lepère [b]

[a] MINES ParisTech, CAOR – Centre de Robotique, Mathématiques et Systèmes,
60 Bd St Michel 75272 Paris Cedex 06, France – (hyun-jae.yoo, francois.goulette, joel.senpauroca)@mines-paristech.fr
[b] MENSI Trimble, 30 rue de la Fontaine du Vaisseau 94120 Fontenay sous Bois, France – gregory_lepere@trimble.com

KEY WORDS: Analysis, Comparison, Simulation, Mobile Mapping System, Laser scanning

ABSTRACT:

Over the past decade, laser terrestrial Mobile Mapping Systems (MMS) have been developing for the digitizing of outdoor environments. While the applications of MMS are various (urban security, road control, virtual world, entertainment, etc.), one may imagine that for each application the system designs could be different. Hence, a comparative analysis of different designs may be useful to find the best solution adapted to each application. We present in this paper a methodology based on the use of a simulator, to compare several designs of MMS and to improve the design. We illustrate it in the case of urban architecture digitizing.

1. INTRODUCTION

Laser mapping systems have been developing for the digitizing of outdoor environments. For the 3D Geographic Information System (3D GIS), point cloud data from laser systems is very useful because they provide directly 3D coordinates data so that is more efficient compared to other systems. There are two types of laser systems according to the dynamism of platform: static mapping systems and mobile mapping systems (MMS).

We can compare static and mobile mapping systems in terms of time. We compared with real systems, total station VX Trimble [TRI web] as static mapping system and LARA-3D (prototype vehicle of MINES ParisTech) as mobile mapping system on the street of Paris [YOO 09]. As the result of this test, we confirm that the mobile mapping system can save lots of time comparing static mapping system (total acquisition time is about 6 hours with static system and about 40 minutes with mobile system for the test zone of 140m x 30m). And it is one of the main reasons to develop these dynamic systems.

However, even if the acquisition time can be saved, if the quality of the data is low, then we can not consider MMS as the useful mapping system. Hence, the design of MMS is necessary to improve the quality of the data. The notion of design involves characteristics, number and spatial configurations (position and orientation) of sensors on the mobile platform. The designs of MMS could be different while the applications are various (urban security, road control, virtual world, entertainment, etc.). For example, VLMS from Tokyo University embeds 3 laser scanners on the back of the vehicle [MAN 00], DAVIDE from GIOVE uses two different types of laser scanner [AMO 07] and StreetMapper from 3D Laser System has several designs varying the number of scanners [HUN 06, 3DLM web]. These all the MMS has different spatial configurations and different types of laser scanner according to the application.

We present in this paper a methodology based on the use of a simulator, to compare several designs of MMS and to improve design and illustrate it in case of urban architecture digitizing.

The use of a simulator to evaluate the different designs is motivated by several reasons. First, we can gain time to test the different designs in simulation, in comparison to the tests in real environment. Secondly, we can optimize the final design before a real test. And also, we can separate the issues related to the perception system from those of the localization system.

2. METHODOLOGY OF COMPARATIVE ANALYSIS

For the comparative analysis, we need several criteria and the score of each design candidate for each criterion. As each application has different level of importance on criteria, we need also the coefficient of each criterion for each application.

In this section, we define several criteria for the quality of point cloud data and the method to give a score. We show an example of coefficient for each criterion for couple of given applications.

2.1 Quality criteria of laser mappings

To compare the data quality, we need several criteria such as precision, resolution, completeness, etc. These criteria are available for both static and mobile mapping systems.

2.1.1 Precision: All the point cloud data needs high level of precision. In this domain, it is necessary to separate the notion of precision in to two: absolute precision and relative precision. The absolute precision is the difference between the real distance to object and the mean of calculated distances. The relative precision is the standard deviation (cf. Figure 1).

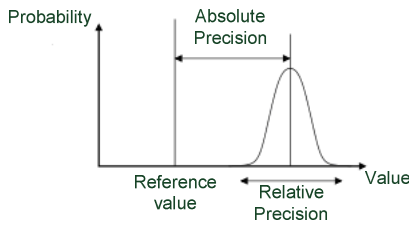

Figure 1: Accuracy and precision

Figure 2 shows the example of the notion of precision. As the absolute position of the data from the scanner has some difference (α) compared to the real position, the (a) and the (b) are in low level of absolute precision. The (a) and the (c) are in low level of relative precision because their point clouds do not represent the object correctly. The (d) is in high level of both absolute and relative precisions.

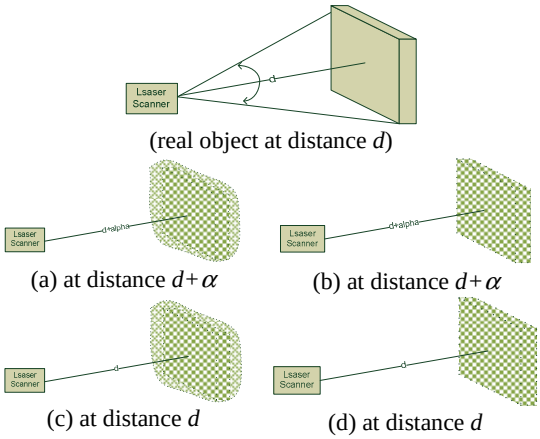

Figure 2: Example for notion of precision

For the MMS, the precision is directly linked to the localization system (especially to absolute precision). If we do not know exactly where we are (i.e. the information from localization system is not accuracy), the precision could not be high.

We propose to give a score with the equation (1) which makes also to classify the precision in several levels like class0: around 1m, class1: around 1dm, class2: around 1cm, class3: around 1mm, etc.

$$N_{abs} = \log_{10} {ref}/{abs}$$
$$N_{rel} = \log_{10} {ref}/{rel} \qquad (1)$$

Where N_{abs} = score for the absolute precision
N_{rel} = score for the relative precision
ref = reference value (which equals to 1 m)
abs = difference between reference value and mean of real values (m)
rel = standard deviation (m)

2.1.2 Resolution: The resolution is defined by demands of users or application domains. For example, the requirement can be ≤ 1dm for all objects. This criterion depends on the vehicle state (speed, orientation) and also the characteristics of laser scanner used (pulse repetition rate, scanning rate).

Density: We can explain resolution by the notion of density. In this domain, we define the density as the number of neighbor points which are the distance is ≤ 1m from the each reference point. This definition deducts the unit of density as "points/m^3" but we permit "points/m²" by assuming that all the neighbor points are projected to the surface circle as Figure 3.

In the case of Figure 3, there are 8 points (points within the distance r = 1 and including the reference point) in the surface of 4π m², hence, the density value of the reference point is 0.63 points/m².

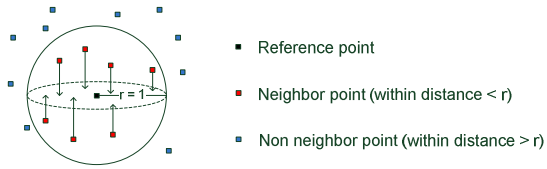

Figure 3: Calculation of density value

The value of general density is the mean of all point densities and it is calculated with equation (2).

$$D_G = \frac{1}{n_T} \cdot \sum_{i=1}^{n_T} D_i$$
$$D_i = \frac{n}{4\pi} \qquad \sum_{i=1}^{n_T} D_i \geq \frac{n_T}{4\pi} \qquad (2)$$

Where D_i = density value of the point *i* (points/m²)
n = number of neighbor points
D_G = general density value (points/m²)
n_T = number of total points of the data

We propose to give a score of density with the equation (3) which makes also to classify the density in several classes like class0: 1 to 10 points/m², class1: 10 to 100 points/m², class2: 100 to 1000 points/m², class3 1000 to 10000 points/m², etc.

$$N_{density} = \log_{10} D_G \qquad (3)$$

Where $N_{density}$ = score for the general density
D_G = general density value (points/m²)

Variation of homogeneity: The quality of the data could be also changed according to the homogeneity. We suppose the data is homogeneous if the point densities of all the data are same (i.e., if the standard deviation is 0).
But as the distance between system and object is often variable, the density can not be constant (over-density if distance is short, under-density if distance is long). Also, for mobile systems, if the vehicle turns on left, left side of platform could be over-density and right side could be under-density.
The under-density causes a problem of lack of information on the scene and the over-density may induce a problem of the data storage. For the static mapping system, there is a technology which resolves this problem (Surescan technology of GX advanced from Trimble) [HOOK 07].

We propose to give a score of homogeneity with the variation of density (Figure 4).

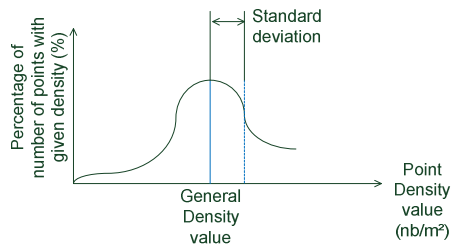

Figure 4: Variation of density

The vertical axe represents the percentage of number of points with given density (%) and horizontal axe represents the value of point density (number of points/m²). In this article, we assume the value of homogeneity is the value from equation (4).

$$X = 1 - \sigma / D_G \quad (4)$$

Where X = value of homogeneity
σ = value of standard deviation (points/m²)
D_G = value of general density (points/m²)

The standard deviation can vary between 0 and D_G (X varies between 0 and 1). If the standard deviation tends to 0, the value of homogeneity tends to 1. It means the data is homogeny.

2.1.3 Completeness: The objective of completeness criterion is to minimize occluded zones in the scene. The occluded zones mean the zones which are necessary to scan but are not scanned during the acquisition.
We propose to give a score for this criterion like percentage, from '0' to '100'. '0' means there are nothing scanned, '100' means the scene is completely scanned (there are no occluded zones). In this article, we give the score for each type of object such as building, bridge, road, etc.
For the mobile mapping systems, we can define two types of occluded zones according to the cause of occlusion: non visible zone and shadow zone. These zones are created from the direction of vehicle.

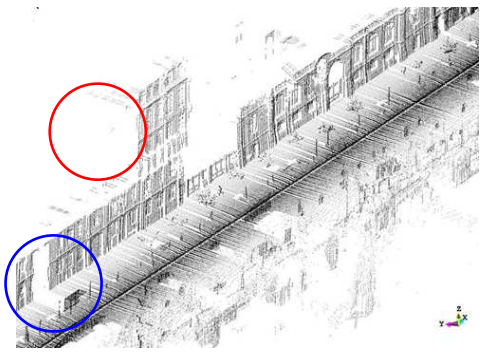

Figure 5: Point cloud with occluded zones [ABU 05]

Figure 5 is the real point cloud from the data acquisition with LARA-3D, MMS prototype of MINES ParisTech. It presents the point cloud data of the facade of "MINES ParisTech" which contains several occluded zones.

Non visible zone: This zone means the zone which is not scanned by MMS even if there is no obstacle. As we can see in Figure 5 with red circle, LARA-3D can not scan the facade whose normal is parallel to the direction of vehicle. This non visible zone could be a critical problem for certain applications such as 3D building modeling which needs the information of all facades.
The non visible zone can be modified if we modify the spatial configuration of scanner. Or if we use several scanners in different spatial configuration, the non visible zone with a scanner can be covered by other scanner(s).

Shadow zone: This zone means the zone which is occluded by objects. For example, if we scan the urban environment, there are several parking cars, pedestrians, trees, bench, etc. in front of buildings make shadow zone on the building facades. As we can see in Figure 5 with blue circle, the parking car has created a shadow zone on the building facade. This shadow zone could cause a critical problem for certain applications.

This zone will not be disappeared if we use only one scanner but could be moved with some modification of spatial configuration of scanner. We need to use several scanners with different spatial configuration to cover the shadow zones which is created by one scanner with other scanners.

2.2 Constraints

There are also several constraints to compare laser mapping systems such as cost, complexity, size, etc. In this article, we do not mention these constraints.

2.3 Normalization of score

After giving the score for each criterion, we need to normalize it because each criterion has different interval score. For example, the score of precision is maximum 4 but the score of completeness is 100. We give new score which is variable between 0 and 10, by the equation (5).

$$N = \frac{x - m}{M - m} \cdot 10 \quad (5)$$

Where N = final score
x = value of design candidate
m = minimum value possible (generally $m = 0$)
M = maximum value possible (or ideal value)

We presented several criteria to compare the data quality of laser mapping systems. We use these criteria to compare several designs of MMS.

2.4 Coefficient proposed for applications

It is necessary to define the application domain for the mapping systems to give the coefficient for each criterion. For example, the application domain can be the architecture for 3D tourism or the road survey, etc.
For each application domain, the coefficients are different. The coefficient is variable between 0 and 10.

Criterion	Sub criteria	Architecture for 3D tourism	Road survey
Precision	Absolute	4	4
	Relative	4	4
Resolution	General density	4	5
	Homogeneity	5	3
Completeness	buildings	4	1
	bridge	3	0
	road	3	3

Table 1: Coefficient of criteria for application domain

Table 1 shows an example of coefficient for each criterion for couple of given applications. We propose high coefficient of the precision criterion (4 for absolute, 4 for relative precision) for both application domains because it is very important criterion whatever the application domain is. We propose different coefficient of the resolution criterion for each application. And we also propose different coefficient of the completeness criterion. For the application "Architecture for 3D tourism", we need to scan all the buildings, bridges, road as perfect as possible. Contrariwise, for the application "Road survey", we need to scan road perfectly but the others (buildings, bridges) are not quite necessary.

The coefficient could be different according to the users even for the same application domain. In this article, we propose one of the several possibilities.

Noting designs for each of these criteria and using coefficients, we end up with a global score for each design of system. The global score is calculated by multiplying the score with coefficient.

3. ILLUSTRATION OF COMPARATIVE ANALYSIS BASED ON SIMULATION

We illustrate our methodology on various designs derived from the existing LARA-3D platform, by changing the number of laser scanners and their spatial configurations (positions and orientations (pitch and yaw)) on the platform.
LARA-3D is the prototype which has been designed and developed by our laboratory. It is composed of two sub-systems: localization system (GPS, INS, etc.) and perception system (laser scanners, cameras, etc.) [GOU 06]. LARA-3D allows us to do prospective studies and to help us in the development of novel designs relative to mobile mapping technologies. This system has been used as a test bed to compare several possible options, using our methodology.

Figure 6: LARA-3D

Figure 6 shows LARA-3D, with one laser scanner on the top of the vehicle with about 2.5m of height. The scanner scans the profile perpendicular to the direction of vehicle.

3.1 Simulator

For the implementation, we have used two software, one dedicated to simulation: SiVIC (Simulator of vehicle, infrastructure and sensors) developed by LIVIC (INRETS / LCPC), adapted to our needs [YOO 09], and RTMaps (Real Time, Multi-sensor, Advanced and Prototyping Software) developed by Intempora [INT web].

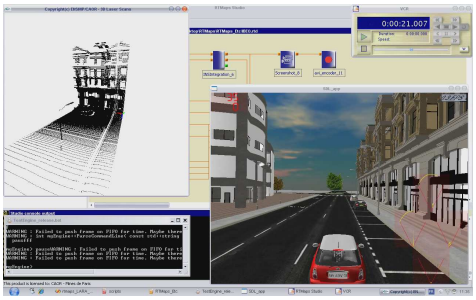

Figure 7: SiVIC and RTMaps

Figure 7 shows the generation of point cloud data during the simulation. Two windows in down side of figure are from SiVIC (left: command window, right: visualization window). Two windows in upper side and the background of figure are from RTMaps (left: point cloud visualization window, right command window, background: RTMaps diagrams).

We suppose that the localization system offers perfect data during all the time (using perfect IMU in simulation).

3.2 Application domain

For this illustration, we choose as application domain the “Architecture for 3D tourism”. For this application, we have the coefficient for each criterion as mentioned in section 2.4.

3.3 Designs

As mentioned, we can imagine several propositions of designs by changing some configuration of sensors for the simulation by changing the number of laser scanners, their position and orientation on the platform, the type of sensor, etc. In this article, we compare three different designs using the same laser scanner. Table 2 shows the characteristics of laser scanner in simulation.

Scanning rate	60 Hz
Angular resolution	0.5°
Field of view	360°
Range	100m (for albedo 20%)

Table 2: Characteristics of laser scanner in simulation

3.3.1 Design #1: For this design, we put the scanner on the top of vehicle with 2,5m of height without inclination like actual LARA-3D. Table 3 shows the spatial configuration of design #1. The values are local value on the vehicle (position (0, 0, 0) is the center of two backside wheels). The position is composed by (direction of the vehicle, lateral, height). The orientation is composed by (angle of raw, pitch and yaw).

Position	-1, 0, 1 (m)
Orientation	0, 0, 0 (°)

Table 3: Configuration for design #1

3.3.2 Design #2: For this design, we put the scanner at the same position of the design #1 but with inclination 20° of pitch (Table 4).

Position	-1, 0, 2.5 (m)
Orientation	0, 20, 0 (°)

Table 4: Configuration for design #2

3.3.3 Design #3: For this design, we use two laser scanners on the corners of platform with some inclination (Table 5). This design is used with several MMS [MAN 00, 3DLM web].

	Scanner 1	Scanner 2
Position	-1, -1, 1.8 (m)	-1, 1, 1.8 (m)
Orientation	0, 20, 45 (°)	0, -20, 45 (°)

Table 5: Configuration for design #3

3.4 Scene

To compare these different designs in simulation, we need to define the virtual scene. As shown in Figure 8, the scene

involves several buildings, bridges, parking cars, trees, pedestrians, etc. We choose the mobile platform (vehicle) speed at 50km/h (13,89m/s) for all the designs of MMS. The movement of vehicle is from right to left.

Figure 8: Virtual scene

3.5 Comparative analysis

Using our methodology proposed above, we do a comparative analysis of different designs of MMS. Table 6 shows the result of this analysis based on simulation (The value between the parentheses is the score before normalization).

Criterion	Coefficient	Design #1	Design #2	Design #3
Absolute Precision	4	N/A	N/A	N/A
Relative Precision	4	N/A	N/A	N/A
General Density	4	6 (1.82)	6.13 (1.84)	7.5 (2.25)
Homogeneity	5	1.4 (0.14)	1.1 (0.11)	1.9 (0.19)
Completeness (buildings)	4	3 (30)	5 (50)	4.5 (45)
Completeness (bridge)	3	2 (20)	4.5 (45)	7 (70)
Completeness (road)	3	9.5 (95)	9.5 (95)	9.5 (95)
Total score	**-**	**77.5**	**92.02**	**107**

Table 6: Comparative analysis table

3.5.1 Precision: As the simulation gives perfect data (both localization and perception systems), we can not give scores for precision criterion in this time.

3.5.2 Resolution: For the criterion of resolution, we have two sub-criteria: general density value and homogeneity value. As the scene is too big ($4.5x10^6$ points for design #1, $4.0x10^6$ points for design #2 and $9.7x10^6$ points for design #3), we take a part of scene ($0.6x10^6$ points for design #1 for example).

We calculate the value of general density by the equation (2). If we take the example of design #1, the value of general density is 66.58 points /m². Using the equation (3), we obtain the score of general density which is 1.82.
To obtain the normalized score, we suppose that the ideal value of general density equals to 3 which means 1000 points/m² and minimum value equals to 0.

As we can see in Figure 9 which represents the histograms of distribution of points according to their value of point density (above for design #1, centre for design #2 and below for design #3), standard deviations (mentioned as σ) are grand, hence, the value of homogeneity is not high. For the example of design #1, we calculate the standard deviation which is 57.13 points/m². Using the equation (4), we obtain the score of homogeneity which is 0.14.
To obtain the normalized score, we define the maximum value of homogeneity equals to 1 and minimum value equals to 0.

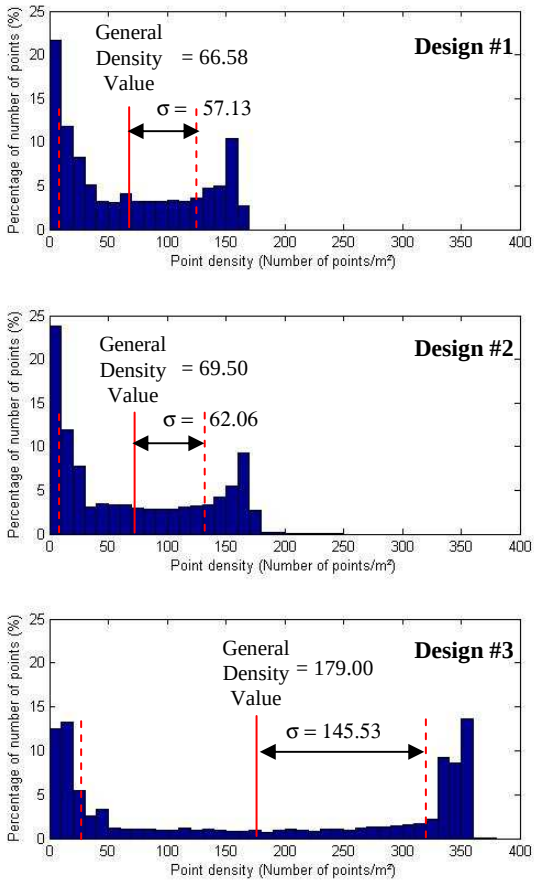

Figure 9: histogram for homogeneity

As shown in Figure 10 which is an example of variation of homogeneity of part of point cloud with Design #2, we have too many points (high density, presented by blue color) in the road zone and not enough points (low density, presented by red color) in the top part of building facades.

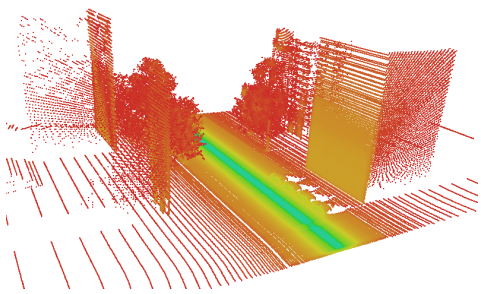

Figure 10: Variation of homogeneity

3.5.3 Completeness: For the criterion of completeness, we have lots of difference between designs. Figure 11, Figure 12 and Figure 13 show the point cloud data of design #1, design #2 and design #3 for the virtual scene presented by false colors (luminance-albedo). In this article, we give scores with approximately as we do not have tools to calculate exactly the completeness yet. This tool will be ready in near future.
To obtain the normalized score, we define the maximum value of completeness equals to 100 and minimum value equals to 0.

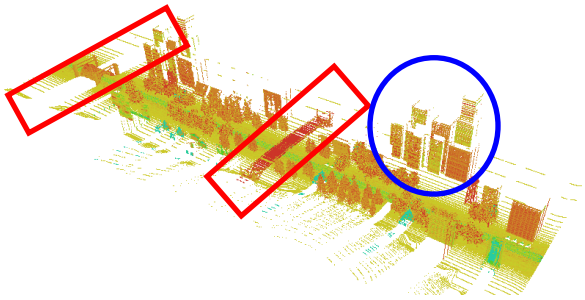

Figure 11: Point cloud of design #1

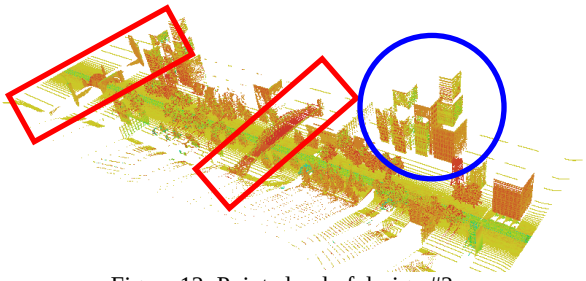

Figure 12: Point cloud of design #2

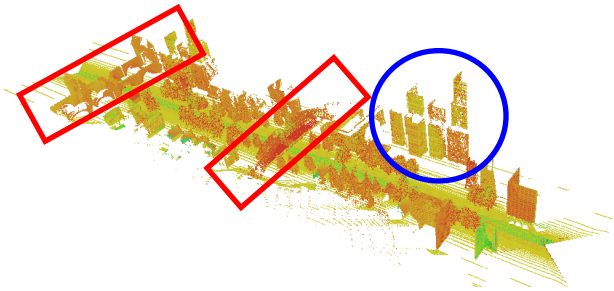

Figure 13: Point cloud of design #3

For buildings, design #1 completes poorly because of non visible zones (blue circle in Figure 11). And even if we use two laser scanners for design #3, we can not cover all the building facades because of shadow zones. For example, as shown in blue circle of Figure 13, buildings which are far from the trajectory of MMS after the buildings which are near were not completely scanned because of the shadow zones made by the near buildings. These missing building facades are scanned by design #2 which has only one laser scanner (blue circle in Figure 12). But even this design can not cover all because of non visible zones (another side of buildings).
We give 30 as the score of design #1 for this criterion because the only the front facades are scanned. We give 50 for design #2 which scanned the one side facades and also the front facades. We give 45 for design #3 which scanned the other side facades and the front facades but less than design #2.

For bridges, design #1 and #2 complete poorly because of too many non visible zones (red rectangles in Figure 11 and Figure 12) which make difficult to do modeling with this data. Contrariwise, data from design #3 provides enough data to do modeling (red rectangle in Figure 13).

As there is no occlusion on the road and the totality of road is visible by all the three designs, enough data is provided.

3.6 Result of analysis

As shown in Table 6, we can conclude that the design #3 is the best solution among them for the application of "Architecture for 3D tourism" with our example of coefficient. But this design is with two laser scanners and it causes some constraints which are not considered for this time (cost, size, etc.).
We can also confirm with the total score of design #1 and design #2 that the modification of spatial configuration of laser scanner can improve the data quality.

4. CONCLUSION AND PERSPECTIVE

We have presented a methodology for the comparative analysis of various designs of mobile mapping systems for a given application. Also, we illustrated the comparative analysis of different designs of MMS using the simulation.

This methodology could be developed and made more precise, adding new criteria (and constraints). The choice of coefficients is important and needs to be adapted to each application. The methodology presented can be used to design and validate new designs of mobile mapping systems.

ACKNOWLEDGEMENTS

The work reported in this paper has been performed as part of the Cap Digital Business Cluster "Terra Numerica" project.

REFERENCES

[ABU 05] I. Abuhadrous, *Système embarqué temps réel de localisation et de modélisation 3D par fusion multi-capteur*, thèse de doctorat, Ecole des Mines de Paris, 2005

[AMO 07] L. Amoureus, M.P.H. Bomers, R. Fuser, M. Tosatto, *Integration of LiDAR and Terrestrial Mobile Mapping Technology for the Creation of a Comprehensive Road Cadastre*, the 5th International Symposium on Mobile Mapping Technology, 29-31 May 2007, Padua

[GOU 06] F. Goulette, I. Abuhadrous, F. Nashashibi, S. Ammoun, C. Laurgeau, *An Integrated On-Board Laser Range Sensing System for On-the-Way City and Road Modelling*, The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, vol. 34, Part A, 2006.

[HUN 06] G. Hunter, C. Cox, J. Kremer, *Development of a Commercial Laser Scanning Mobile Mapping System – StreetMapper*, Second International Workshop The Future of Remote Sensing, 17-18 October 2006, Antwerp

[INT web] http://www.intempora.com

[MAN 00] D. Manandhar, R. Shibasaki, *Geo-referencing of Multi-sensor Range Data for Vehicle-borne Laser Mapping System (VLMS)*, 21st Asian Conference on Remote Sensing (ACRS), Vol 2, pp. 932-937, 4-8 December, Taipei

[HOOK 07] B. Hook, G. Lepère, *Trimble surescan technology white paper*, Trimble Survey, Westminster, Colorado, October 2007

[TRI web] http://www.trimble.com/spatialimaging.shtml

[YOO 09] H.J. Yoo, F. Goulette, J. Senpauroca, G. Lepère, D. Gruyer, *Aide à la conception par simulation de systèmes de cartographie mobiles à scanner laser*, Accepted for publication « Revue Française de Photogrammétrie et de Télédétection ».

[3DLM web] http://www.3dlasermapping.com/