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

Simulação baseada numa análise comparativa para o projeto de um sistema movel de mapeamento terrestre a laser.

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ABSTRACT

Over the past decade, laser terrestrial Mobile Mapping Systems (MMS) have been developed for the digital mapping 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. The objective of this paper is to propose a methodology to compare point-cloud data quality from different MMS designs by modifying spatial configuration of laser imaging system. For this methodology, we define several quality criteria such as precision, resolution, completeness. We illustrate this in the case of urban architecture digital mapping based on the use of a simulator.

Keywords: Analysis; Comparison; Simulation; Mobile Mapping System; Laser scanning.

1. INTRODUCTION

Laser mapping systems have been developed for the digital mapping of outdoor environments. For 3D Geographic Information Systems (3D GIS), point cloud data from laser systems are very useful because they provide directly 3D coordinate data; so this is more efficient compared to other systems. There are two types of laser systems depending on the platform dynamics: 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, the Trimble VX total station (http://www.trimble.com/) as a static mapping system and the LARA-3D (MINES ParisTech prototype vehicle) as a mobile mapping system on the streets of Paris (Yoo et al., 2009). As a result of this trial, we confirm that the mobile mapping system can save a significant amount of time compared to static mapping systems (total acquisition time is about 6 hours with the static system and about 40 minutes with the mobile system for the test zone of 140m x 30m). This is one of the main reasons to develop such dynamic systems.

However, even if acquisition time can be saved, if the quality of the data is low, then we can not consider MMS as a useful mapping system. Hence, research in the MMS design 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. Though MMS designs may differ, the applications are various (urban security, road survey, virtual world, entertainment, etc.). For example, VLMS from Tokyo University embeds 3 laser scanners on the back of a vehicle (Manandhar et al., 2000), DAVIDE from GIOVE uses two different types of laser scanners (Amoureus et al. 2007) and StreetMapper from 3D Laser System has several designs varying the number of scanners (Hunter et al., 06; http://www.3dlasermapping.com/). All these MMS systems have 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 MMS designs to improve the design, and illustrate it in the case of urban architecture digital mapping.

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 tests in the real environment. Secondly, we can optimize the final design before a real test. And also, we can separate the issues related to imaging systems from those of the navigation 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 a different level of

importance on criteria, we need also to define 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 coefficients for each criterion for combinations of given applications.

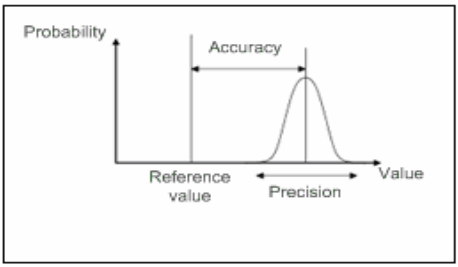
2.1 Quality Criteria of Laser Mappings

To compare 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 Accuracy and precision

All the point cloud data need high levels of accuracy and precision. The accuracy is the difference between the real distance to object (reference value) and the mean of calculated distances. The precision is the standard deviation (Figure 1).

Figure 1 – Accuracy and precision.



For MMS, accuracy and precision are directly linked to the navigation system (especially accuracy). If we do not know exactly where we are (i.e. the information from the navigation system is not accurate), the accuracy and the precision cannot be guaranteed.

We propose to give a score with the equation (1) which allows classification of precision at several levels like class 0: around 1 m, class 1: around 1 dm, class 2: around 1 cm, class 3: around 1 mm, etc.

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

Where N_a = score for accuracy
N_p = score for precision
ref = reference value (which equals to 1 m)

abs = difference between reference value and mean of real values (m)

rel = standard deviation (m)

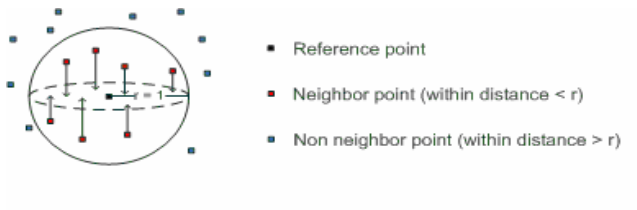
2.2.2 Resolution

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

Density: We can explain resolution by the notion of density. In this domain, we define density as the number of neighbor points whose distance is ≤ 1 m from each reference point. This definition deduces the density unit as "point/m^3" but we permit "points/m²" by assuming that all the neighbor points are projected to the surface circle as Figure 2.

In the case of Figure 2, there are 8 points (points within the distance r = 1 m and including the reference point) in the surface of π m², hence, the density of the reference point is 8/π = 2.55 points/m².

Figure 2 – Calculation of point density.



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

$$\overline{D} = \frac{1}{n_T} \cdot \sum_{i=1}^{n_T} D_i \qquad (2)$$

Where D_i = density of the point *i* (points/m²)

n = number of neighbor points

$\overline{D}$ = mean density (points/m²)

n_T = total number of points of the data

We propose giving a density score with the equation (3) which allows classification of density in several classes like class 0: 1 to 10 points/m², class 1: 10

to 100 points/m², class 2: 100 to 1000 points/m², class 3 1000 to 10000 points/m², etc.

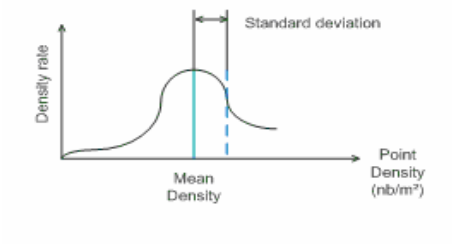
$$N_{density} = \log_{10} \overline{D} \tag{3}$$

Where $N_{density}$ = score for the mean density
$\overline{D}$ = mean density value (points/m²)

Variation of homogeneity: The quality of the data could also be changed according to the homogeneity. We assume the data is homogeneous if the point densities of all the data are the 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 left, the left side of the platform could have an over-density while the right side could have an under-density.
Under-density results in lack of information on the scene and over-density may induce a problem of data storage. For the static mapping system, there is a technology which attenuates this problem (Surescan technology in the Trimble GX Advanced scanner) (Hook et al., 2007).

We propose to give a score of homogeneity with the variation of density (Figure 3).

Figure 3 – Variation of density.



The vertical axis represents the density distribution rate and the horizontal axis represents the point density (number of points/m²). In this article, we assume the value of homogeneity is the value from equation (4).

$$X = 1 - \sigma / \overline{D} \tag{4}$$

Where X = value of homogeneity
σ = standard deviation for density (points/m²)
$\overline{D}$ = mean density (points/m²)

If the standard deviation tends to 0, the value of homogeneity tends to 1. This means the data is homogenous.

2.1.3 Completeness

The objective of completeness criterion is to minimize occluded zones in the scene. Occluded zones mean the zones which are necessary to be scanned 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 is nothing scanned, ‘100’ means the scene is completely scanned (there are no occluded zones). In this article, we estimate the score for each type of object such as building, bridge, road, etc. (the calculation of score needs to be developed further).

For 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 4 – Point cloud with occluded zones (Abuhadrous, 2005).

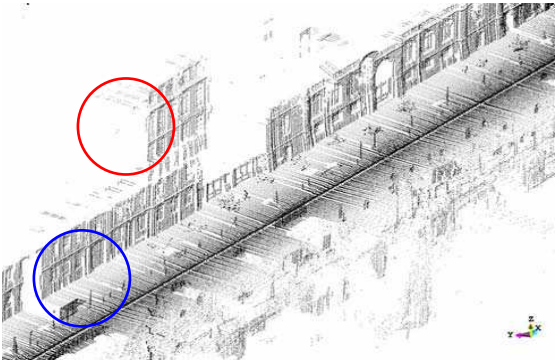


Figure 4 is a point cloud obtained from the data acquisition with LARA-3D, MMS prototype of MINES ParisTech. It presents the point cloud data of the facade of “MINES ParisTech” which contains several occluded zones.

Non visible zone: This zone refers to a zone which is not scanned by MMS even if there is no obstacle. As we can see in Figure 4 with the 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 where complete façade information is required.

The non visible zone can be modified if we modify the spatial configuration of the scanner. Or if we use several scanners in different spatial configurations, the non visible zone with a scanner can be covered by another scanner.

Shadow zone: This zone refers to a zone which is occluded by objects. For example, if we scan the urban environment, there may be parked cars, pedestrians, trees, benches, etc. in front of buildings that cause shadow zones on the building facades. As we can see in Figure 4 with the blue circle, the parked 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 disappear if we use only one scanner but could be removed with some modification of the spatial configuration of the scanner. We need to use several scanners with different spatial configurations to cover the shadow zones which are 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 consider these constraints but focus on spatial geometric configuration of imaging sensors.

2.3 Normalization of score

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

$$N = {x - m}/{M - m} \cdot 10 \tag{5}$$

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

2.4 Coefficient for Applications

According to the application domain, some criteria become more important than others. Hence it is necessary to determine the coefficient for each criterion for a given application domain. The coefficients are applied to calculate the total score of each candidate for a given application. Table 1 is an example of coefficients for the domain of “Architecture for 3D tourism”. We give the coefficient for each sub criterion.

Table 1 – Example of coefficient.

Criterion	Sub criteria	Architecture for 3D tourism
Accuracy & Precision	Accuracy	4
	Precision	4
Resolution	Mean density	4
	Homogeneity	5
Completeness	buildings	4
	bridge	3
	road	3

Noting designs for each of these criteria and using coefficients, we end up with a global score for each system design. The total score is calculated by multiplying the normalized score with a 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: the navigation system (GPS, INS, etc.) and the imaging system (laser scanners, cameras, etc.) (Goulette et al., 2006). 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 5 – LARA-3D

Figure 5 shows LARA-3D, with one laser scanner on the top of the vehicle at a height of 2.5 m. The scanning direction is perpendicular to the vehicle direction.

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 et al., 2009), and RTMaps (Real Time, Multi-sensor, Advanced and Prototyping Software) developed by Intempora (http://www.intempora.com).

Figure 6 – SiVIC and RTMaps.

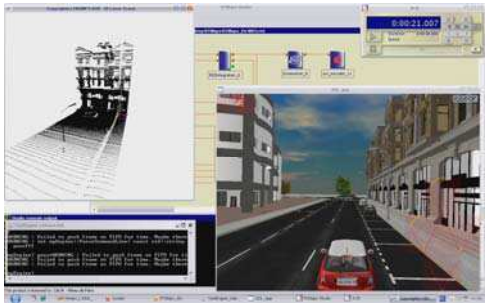


Figure 6 shows the generation of point cloud data during the simulation. The two windows in the lower part of the figure are from SiVIC (left: command window, right: visualization window). The two windows in the upper part and the background of the figure are from RTMaps (left: point cloud visualization window, right: command window, background: RTMaps diagrams).

As we are studying the comparison of different MMS designs (configuration of laser scanners on the platform), we assume that the navigation system offers perfect data during the whole time (using perfect IMU in simulation) and that there is no calibration error between navigation and imaging systems so that all designs have the same level of accuracy and precision.

3.2 Application Domain

For this illustration, we choose as application domain “Architecture for 3D tourism”. For this application, we have the coefficient for each criterion as mentioned in section 0.

3.3 Designs

As mentioned, we can imagine several design propositions by changing the sensors configuration 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 laser scanner characteristics in simulation.

Table 2 – Characteristics of laser scanner in simulation

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

Design #1: For this design, we put the scanner on the top of the vehicle at a height of 2.5 m without inclination, like the current LARA-3D. Table 3 shows the spatial configuration of design #1. The values are local values on the vehicle (position (0, 0, 0) is the center of the rear axle). The position is composed by (direction of the vehicle, lateral direction, height). The orientation is composed by (angle of raw, pitch and yaw).

Table 3 – Configuration for design #1

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

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

Table 4 – Configuration for design #2

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

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 (Manandhar et al., 2000; http://www.3dlasermapping.com/).

Table 5 – Configuration for design #3

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

3.4 Scene

To compare these different designs in simulation, we need to define the virtual scene. As shown in Figure 7, the chosen scene involves several buildings, bridges,

parked cars, trees, pedestrians, etc. We chose a mobile platform (vehicle) speed of 50 km/h (13.89 m/s) for all the MMS designs. Vehicle movement is from right to left.

Figure 7 – Virtual scene

3.5 Comparative Analysis

Using the methodology proposed above, we perform a comparative analysis of different MMS designs. Table 6 shows the result of this analysis based on simulation (The value between the parentheses is the score before normalization). We used the coefficient of "Architecture for 3D tourism" shown in Table 1.

Table 6 – Comparative analysis table

Criterion	Coefficient	Design #1	Design #2	Design #3
Accuracy	4	N/A	N/A	N/A
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**

Accuracy and precision: As the simulation gives perfect data (both navigation and imaging systems) in this experiment, we do not provide scores for the precision criterion.

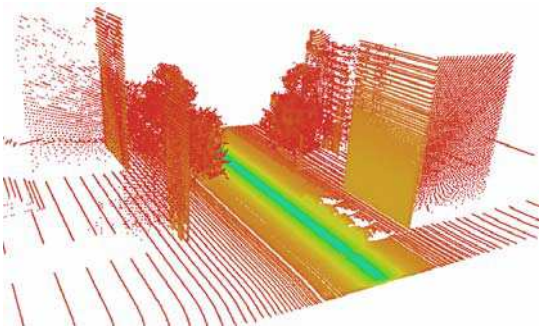
Resolution: For the criterion of resolution, we have two sub-criteria: mean density and homogeneity value. As the scene is very large ($4.5x10^6$ points for design #1, $4.0x10^6$ points for design #2 and $9.7x10^6$ points for design #3), we take a part of the scene ($0.6x10^6$ points for design #1 for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

We calculate the mean density by the equation (2). If we take the example of design #1, the value of mean density is 66.58 points /m². Using the equation (3), we obtain the score of mean density which is 1.82.

To obtain the normalized score, we assume that the ideal value of mean density is equal to 3 which means 1000 points/m² and minimum value is equal to 0.

As shown in Figure 8 which is an example of variation of homogeneity of part of point cloud with Design #2, we have too many points (high density, shown in blue color) in the road zone and not enough points (low density, shown in red color) in the top part of building facades.

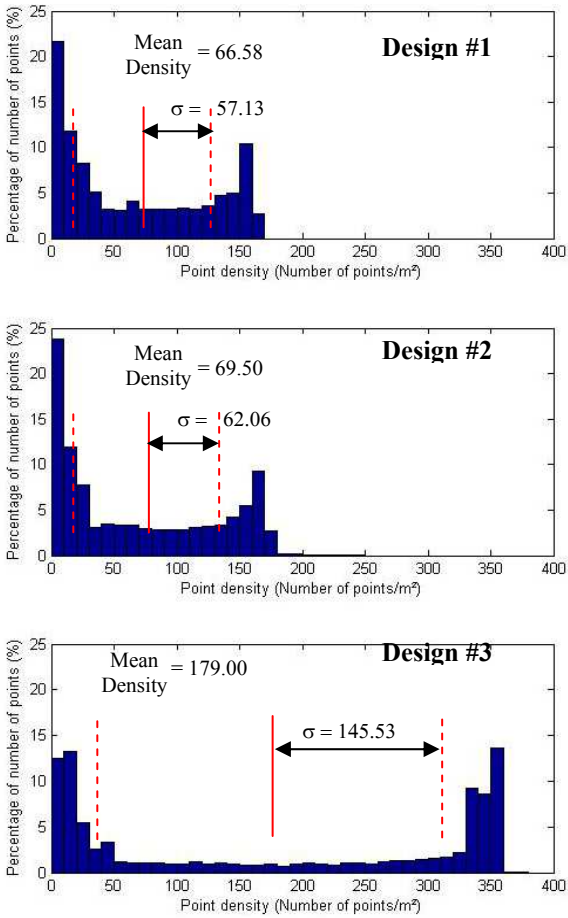
Figure 8 – Variation of homogeneity



As we can see in Figure 9 which represents the histograms of distribution of points according to their value of point density (top for design #1, centre for design #2 and bottom for design #3), standard deviations (mentioned as σ) are high, 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 as equal to 1 and minimum value equal to 0.

Figure 9 – histogram for homogeneity



Completeness: For the criterion of completeness, we have significant differences between designs. Figure 10, Figure 11 and Figure 12 show the point cloud data of design #1, design #2 and design #3 for the virtual scene presented by false colors (albedo). In this article, we give approximate scores as we do not currently have tools to calculate exactly the completeness. Such a tool is under development.

To obtain the normalized score, we define the maximum value of completeness as equal to 100 % and minimum value equal to 0 %.

Figure 10 – Point cloud of design #1

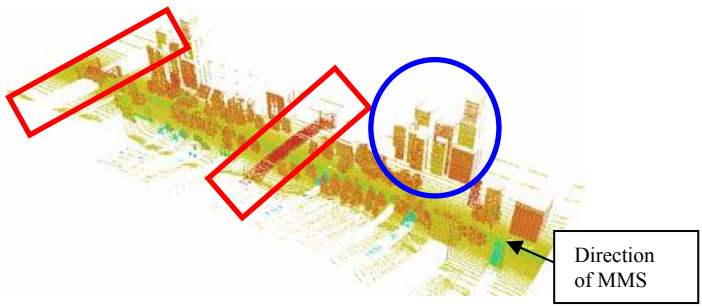


Figure 11 – Point cloud of design #2

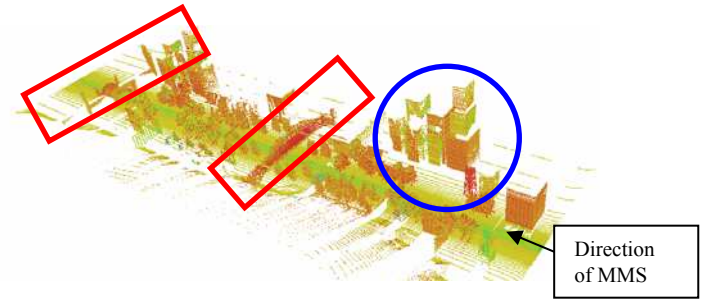
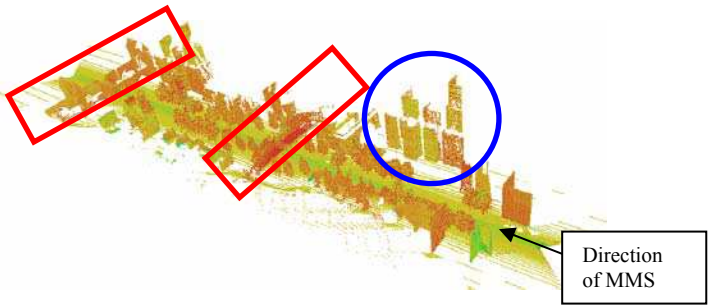


Figure 12 – Point cloud of design #3



For buildings, design #1 completes poorly because of non visible zones (blue circle in Figure 10). 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 the blue circle of Figure 12, buildings which are further from the trajectory of MMS than others 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 11). But even this design can not cover all because of non visible zones (another side of buildings).

We estimate at 30 % the score of design #1 for this criterion because only the front facades are scanned (100 % would correspond to a complete scan of all front facades and two side-facades of buildings). We estimate at 50 % the score of design #2, which scanned one side of the facades and also the front facades. We estimate at 45 % the score of 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 10 and Figure 11) which makes modeling with this data more difficult. On the other hand, data from design #3 provides enough data to carry out modeling (red rectangle in Figure 12).

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

3.6 Results of the Analysis

As shown in Table 6, we can conclude that design #3 is the best solution among all for the application of "Architecture for 3D tourism" with our example of coefficients. But this design is with two laser scanners and it causes some constraints which are not considered at this time (cost, size, etc.).

We can also confirm with the total score of design #1 and design #2 that a simple modification of spatial configuration of the laser scanner can improve the data quality.

4. CONCLUSION AND PERSPECTIVE

We have presented a methodology for comparative analysis of point cloud data quality from various designs of mobile mapping systems. We have defined several criteria for this analysis, for a given application, and proposed their score calculation. This has been illustrated using simulation.

The methodology presented can be used to design and validate new concepts of mobile mapping systems for a given target of data quality.

This methodology needs to 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. Further developments are considered to complement the tools for computation of these criteria on specific data.

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