ANALYSIS AND IMPROVEMENT OF LASER TERRESTRIAL MOBILE MAPPING SYSTEMS CONFIGURATIONS

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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 is useful to find the best solution adapted to each application. The objective of this paper is to analyze several MMS designs with a new methodology based on the use of a simulator in order to compare and to improve the design. We conclude by showing the first results of a prototyped system with a design dedicated for urban modeling application.

1. INTRODUCTION

Laser mapping systems have been classically 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 have performed a comparison with real systems, the Trimble VX total station [TRI web] as a static mapping system and the LARA-3D (MINES ParisTech prototype vehicle) as a mobile mapping system on the streets of Paris [YOO 09a]. 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 inadequate, then we finally 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 [MAN 00], DAVIDE from GIOVE uses two different types of laser scanners [AMO 07] and StreetMapper from 3D Laser System has several designs varying the number of scanners [HUN 06, 3DLM web]. 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 show our experimental results of a prototyped system. We focus on spatial geometric configuration of laser scanners in this paper.

2. COMPARATIVE ANALYSIS OF LASER DATA

We have developed a methodology for comparative analysis of laser data, for both static and mobile scanning systems. The comparative analysis allows us to compare different designs imagined for a given application. We define several criteria for this analysis. Noting the configurations for each of these criteria and using coefficients, we end up with a global note for each configuration. It is necessary to define an application domain for MMS with the requirements and restrictions to give the coefficient for each criterion [Yoo 09b]. The application domain considered in the following is the urban modeling application.

In this section, we define briefly several criteria for the quality of point cloud data and the method to give a score.

2.1 Quality criteria of laser data

We define three quality criteria of laser data: precision, resolution and completeness. In order to compare several designs, we have developed a method to give a score (quantitative value) to each criterion.

2.1.1 Precision: This criterion is composed with accuracy and precision sub-criteria. All the point cloud data need high levels of accuracy and precision.

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

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

Where
N_a = score for accuracy
N_p = score for precision
ref = reference value (m)
abs = difference between true value and mean of acquired values (m)
rel = standard deviation (m)

2.1.2 Resolution: This criterion is explained by density and homogeneity sub-criteria.

Density: We define density as the number of neighbor points whose distance is inferior to a reference distance (we choose 1 m for the reference distance according to our experimental results) from each reference point. The mean density is the mean of all point densities and is calculated with equation (2).

$$\overline{D} = \frac{1}{n_T} \cdot \sum_{i=1}^{n_T} D_i \quad \text{with} \quad D_i = \frac{n_i}{\pi \cdot r^2}$$
(2)

Where
D_i = density of the point i (points/m²)
n_i = number of neighbor points for point i
r = reference distance (m)
$\overline{D}$ = mean density (points/m²)
n_T = total number of points of the data

We propose giving a density score with equation (3) which allows classification of density in several classes: 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.

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

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

Homogeneity: We assume that the data are homogeneous if the point densities of all the data are the same (i.e., 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 shorter, under-density if distance is longer). 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 07].
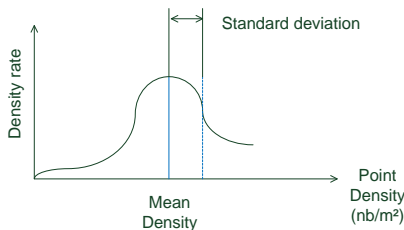

Figure 1: Variation of density

We propose to give a homogeneity score with the variation of density (Figure 1). The vertical axis represents the density distribution rate and the horizontal axis represents the value of point density (number of points/m²). We define the homogeneity score with equation (4).

$$X = 1 - \frac{\sigma}{D}$$
(4)

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

If the standard deviation tends to 0, the homogeneity score tends to 1. This means the data are homogenous.

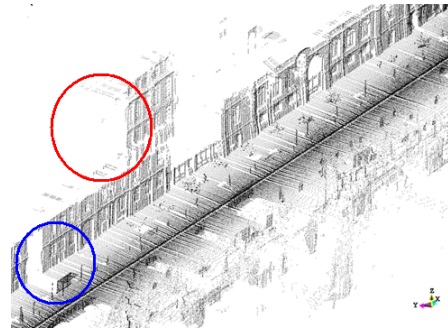**2.1.3 Completeness**: This criterion is explained by two notions of occluded zone.

Figure 2: Point cloud with occluded zones [ABU 05]

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 2 with the red circle, there is no information of façade which does not have any measurement because of the important incident angle (around 90°) between the direction of laser and the façade. 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 (or removed) 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 2 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.

We propose to give a score for this criterion like percentage, from '0' to 100 % by estimating the coverage of zone. 0 % means there is nothing scanned (all is occluded), 100 % means the scene is completely scanned (there are no occluded zones).

2.2 Normalization of score

As each criterion has a different interval score, we normalize it. We give a normalized score which is variable between 0 and 10, by equation (5).

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

Where

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

2.3 Coefficient proposed for applications

As the importance of each criterion can be varied for application, it is necessary to define the application domain to give the coefficient for each criterion (for example, architecture for 3D tourism or road survey, etc.).

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

3. IMPROVEMENTS AND EXPERIMENTAL RESULTS

Using the presented methodology, we analyze several designs of MMS based on simulation, by changing their positions and orientations on the platform. The chosen design will be set up on LARA-3D which 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.) [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 3: LARA-3D

Figure 3 shows LARA-3D, with one laser scanner on the top of the vehicle at a height of 2.5m.

3.1 Simulator

The use of a simulator to evaluate the different concepts is motivated by several reasons. First, we can gain time to test the different concepts in simulation, in comparison to actual tests. Secondly, we can optimize the final concept before a real test. And also, we can separate the issues related to imaging systems from those of the navigation system. For the implementation of simulation, we have used two software: SiVIC (Simulator of vehicle, infrastructure and sensors) developed by LIVIC (INRETS/LCPC), adapted to our needs [YOO 09a] and RTMaps (Real Time, Multi-sensor, Advanced, and Prototyping Software) developed by Intempora [INT web].

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 Designs

As mentioned, we can imagine several design propositions by changing the sensors configuration for the simulation by changing their position and orientation on the platform, or by changing the operational parameters during scanning like scanning rate, angular resolution and vehicle speed. In this paper, we compare three different designs using one or two identical laser scanners and keeping constant the operational parameters. Table 1 shows the laser scanner characteristics in simulation. The angular resolution

Scanning rate	60 Hz
Angular resolution	0.5°
Field of view	180°
Range	100m (for albedo 20%)

Table 1: Characteristics of laser scanner in simulation

For the three designs, we put scanner(s) on the top of the vehicle at a height of 2.5 m. We use two scanners for one side of the scene (for design #2 and #3).
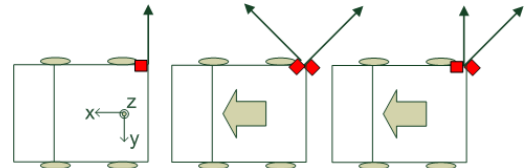

Figure 4: designs of MMS

3.2.1 Design #1 (reference): This design is the reference design. For this design, one scanner is positioned without inclination, like the current LARA-3D (Figure 4 left). Table 2 shows the spatial configuration of design #1. These 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 (x), lateral direction (y) and height (z). The orientation is composed of three angles (roll, pitch, yaw).

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

Table 2: Configuration for design #1

3.2.2 Design #2: For this design, two scanners are positioned as in the center image of Figure 4. Table 3 shows the spatial configuration of design #2.

	Scanner 1	Scanner 2
Position	-1, -1, 2.5 (m)	-1, -1, 2.5 (m)
Orientation	0, 20, 45 (°)	0, 20, -45 (°)

Table 3: Configuration for design #2

3.2.3 Design #3: For this design, two scanners are positioned as in the right image of Figure 4. Table 4 shows the spatial configuration of design #3.

	Scanner 1	Scanner 2
Position	-1, -1, 2.5 (m)	-1, -1, 2.5 (m)
Orientation	0, 20, 0 (°)	0, 20, 30 (°)

Table 4: Configuration for design #3

3.3 Application

The application which has been selected to demonstrate the methodology is urban modeling. For this application, we want to scan the entire city. Other applications could be urban security, road control, etc. Hence, we define a virtual scene which involves several buildings, bridges, parked cars, trees, pedestrians, etc. (Figure 5).

For the operational parameters, we chose the vehicle speed of 50 km/h (13.89 m/s) for all the MMS designs and the scanning rate and the angular resolution are fixed at the values of Table 1.

Figure 5: Virtual scene

3.4 Comparative analysis

Using the methodology mentioned above, we perform a comparative analysis of different MMS designs. Table 5 shows the result of this analysis based on simulation. We used the coefficients adapted to our application (Table 5).

Criterion	Coefficient	Design #1	Design #2	Design #3
Accuracy	4	N/A	N/A	N/A
Precision	4	N/A	N/A	N/A
Mean Density	4	8.39	9.23	7.93
Homogeneity	3	3.57	2.15	0.05
Visibility	5	5	7.5	9
Non shadowing	5	5	3.5	7
Total score	-	**94.27**	**98.37**	**111.87**

Table 5: Comparative analysis table

3.4.1 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.

3.4.2 Resolution: As the scene is very large, we take a part of the scene. We calculate the mean density using equation (2). For example, the mean density is 327.73 points /m² for design #1. Using equation (3), the score of mean density is 2.52.

To obtain the normalized score, we assume that the ideal score of mean density is equal to 3 (1000 points/m²) and minimum score is equal to 0. Hence, we obtain 8.39 as the normalized score of mean density for design #1.

As shown in Figure 6 which is an example of variation of homogeneity in a point cloud with Design #1, 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.
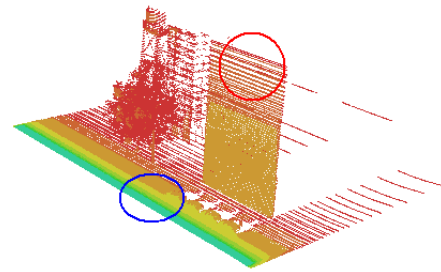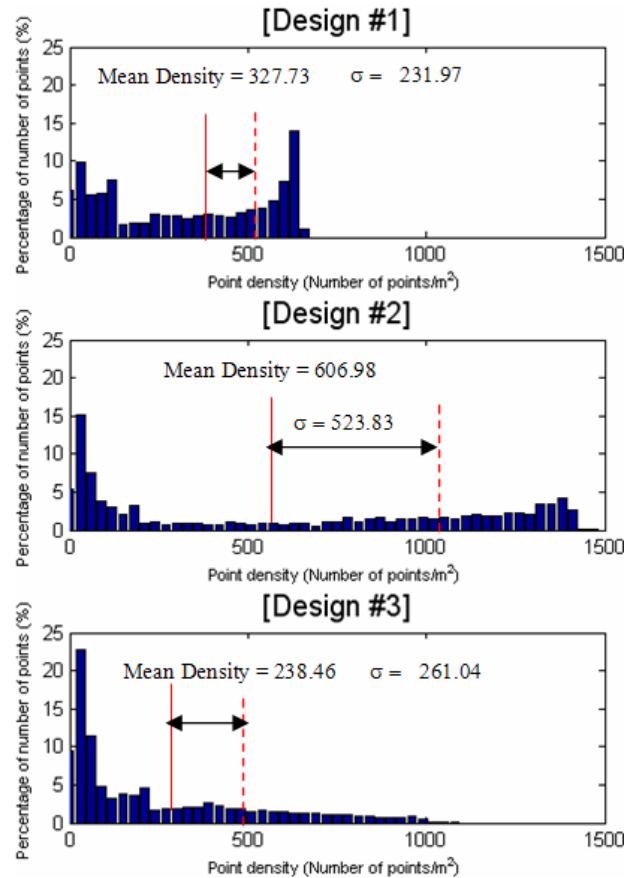

Figure 6: Variation of homogeneity

Figure 7: histogram for homogeneity

As we can see in Figure 7 which represents the histograms of distribution of points according to their point density, standard deviations (σ) are high, hence, the homogeneity score is not high. For design #1, the standard deviation is 231.97 points/m². Using equation (4), the homogeneity score is 0.29. We define the maximum homogeneity score to 1 and minimum score to -0.1 to obtain the normalized score (2.9 for design #1).

3.4.3 Completeness: To evaluate this criterion, we choose three cases of scene: cross-road, U-form building and buildings with different distances from MMS trajectory. These cases are often present in urban environments.
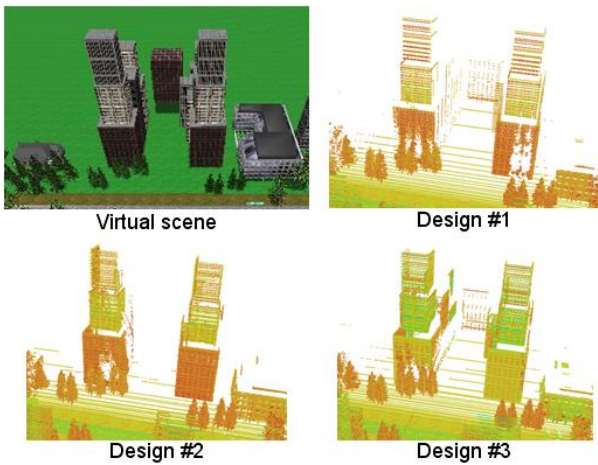
Figure 8: Cross road case

As the virtual scene image of Figure 8, the cross road case is made by two sets of buildings with some distance and a simple building at the end of the road. The MMS is driven from the right to the left side of the scene.

Figure 8 includes three point-clouds data of the cross road case. Design #1 generates data with many occluded zones. Except the front side of buildings, all the other sides of building sets are non visible zones. Only the road and the simple building at the end of the road show it is a cross road scene. Trees in front of the buildings create shadows on the building façade.

Design #2 seems to generate data which is not better than the one from design #1. Thanks to its configuration, the non visible zones for design #1 are minimized but it makes lots of shadow zones. Each set of buildings create shadow on another set of buildings. And there are new non-visible zones on the road and the simple building at the end of the road. With these data, we have difficulty in identifying if it is a cross road scene.

Design #3 generates much more data than others. Even if there are still some shadow zone created by trees, non visible zones for design #1 are minimized thanks to its configuration and no more new non visible zones (road and the simple buildings are scanned correctly). With these data, we can identify that it is a cross road scene with sufficient information for the application.
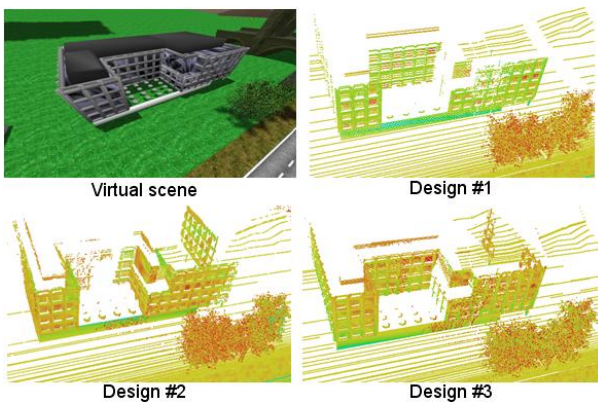

Figure 9: U-form building case

The second case is the U-form building (the virtual scene image of Figure 9). Some parts of building are occluded by trees from the direction of the vehicle.

Figure 9 includes three point-clouds data of the U-form building case.

The point cloud from design #1 has many non visible zone and trees create shadow zone on the building façade. It is too difficult to understand the form of this building.

Design #2 reduced a lot the non visible zone for design #1. But there are new non visible zone at the center of the building and some part are occluded by trees. These data allow understanding the form of the building but it is not convenient to lack the information of building center which is normally easy to get.

The point cloud from design #3 is better than from design #2. We have all parts of the building. These data allow identifying the form of the building correctly.
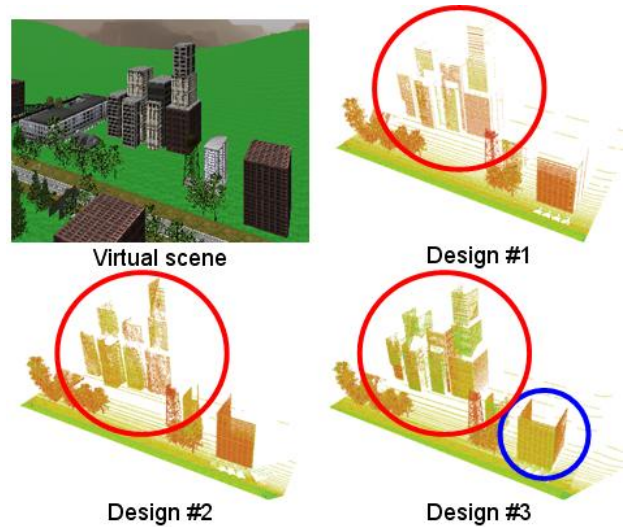

Figure 10: long distance buildings case

The third case is long distance buildings after short distance buildings (the virtual scene image of Figure 10). The direction of the vehicle is from the right to the left side of the scene.

Figure 10 includes three point-clouds data of the long distance buildings case (in red circles).

Design #1 provides only front side of the buildings. There is no influence of the distance for the completeness criterion.

Design #2 provides also front side of the buildings. It must be better than design #1 but the short distance buildings create the shadow zones on the long distance buildings. Hence, there is no significant improvement regarding to design #1.

Design #3 provides data richer than others. We can understand the scene better. We can see also (in blue circle in Figure 10) that design #3 can obtain all three façades of simple building in one passage.

Table 6: Completeness table

Design	#1	#2	#3
Visibility	50 %	75 %	90 %
Non shadowing	50 %	35 %	70 %

Table 6 gives the scores for the criterion of completeness. As design #1 is the reference, we give 50 % (each visibility and non shadowing criterion) and we estimate scores for other designs regarding the reference design. For the visibility, designs #2 and #3 cover the non visible zone for design #1 but design #2 create some new non visible zone. So we give 75 % for design #2 and 90 for design #3. For non shadowing, design #3 remove some parts of shadow zone for design #1 contrariwise, design #2 create lots of shadow zone even more

than design #1. So we give 35 % for design #2 and 70 % for design #3.

As shown in Table 5, we can conclude that design #3 is the best solution among all for our application.

3.5 Prototype on non-motorized cart

With the chosen design (design #3), we have prototyped a system on non-motorized cart (Figure 11) without navigation system. This prototype is to validate the design before the integration on LARA-3D. .

Figure 11: Prototype on chariot platform

We use scanners whose characteristics are similar to Table 1 except the angular resolution which is 0.25°. Scanners are mounted with the configuration mentioned in Table 4 (except the height which is about 1 m). Our test is done on a straight road with constant speed (0.2 m/s).

We scanned a simple building and we got the three sides of the building (Figure 12).
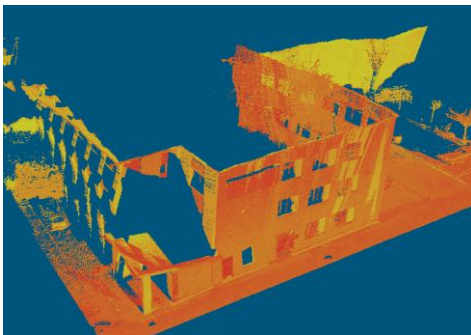

Figure 12: Point-cloud from prototype

The density score of this point cloud is 3.91 (8139.20 points/m²) and the homogeneity score is 0.56 (standard deviation is 3588.47 points/m²). If we use the same conditions of normalization as the paragraph 3.4.2, the normalized scores are 10 for mean density (in class 3) and 5.99 for homogeneity.

To validate this analysis in real situation, we need to integrate the laser scanners on LARA-3D with different configurations.

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 MMS designs using simulation. With this analysis, we can conclude that one design is the most efficient among all for

a given application. And we are now in the process of validation of this design with a prototype.

This methodology could be developed and made more precise, adding new criteria. The choice of coefficients is important and needs to be adapted to each application.

We intend to do a validation test for the chosen design with LARA-3D in real situation.

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