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To cite this version:

Iyad Abuhadrous, Samer Ammoun, Fawzi Nashashibi, Francois Goulette, Claude Laurgeau. Digitizing and 3D Modeling of Urban Environments and Roads using Vehicle-Borne Laser Scanner System. International Conference on Intelligent Robots and Systems (IROS), IEEE/RSJ, Oct 2004, Sendai, Japan. hal-01259652

HAL Id: hal-01259652

https://hal.science/hal-01259652

Submitted on 21 Jan 2016

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Digitizing and 3D Modeling of Urban Environments and Roads using Vehicle-Borne Laser Scanner System

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***Abstract*—In this paper we present a system for three-dimensional environment modeling. It consists of an instrumented vehicle equipped with a 2D laser range scanner for data mapping, and GPS, INS and odometers for vehicle positioning and attitude information. The advantage of this system is its ability to perform data acquisition during the vehicle navigation; the sensor needed being a basic 2D scanner with opposition to traditional expensive 3D sensors. This system integrates the laser raw range data with the vehicle's internal state estimator and is capable of reconstructing the 3D geometry of the environment by real-time geo-referencing.**

We propose a high level representation of the urban scene while identifying automatically and in real time some types of existing objects in this environment. Thus, our modeling is articulated around three principal axes, the segmentation; decimation; the 3D reconstruction and visualization. The road is the most important object for us; some road features like the curvature and the width are extracted.

Keywords: laser-range scanner, urban 3D model, geo-referencing, real-time reconstruction, segmentation, visualization, road papameters, ^{RT}MAPS.

I. INTRODUCTION

The goal of this work is to develop a system able to generate and reconstruct 3D models for urban environments (especially roads) in real time. The data obtained by this system could be good resources for developing urban 3-D databases, which have numerous military and civil applications such as navigation, training and simulation, virtual reality planning, video and computer games, etc.

In general, there are two different techniques for measuring 3D geometrical data. One is based on intensity image; the other is based on range data. Several researches using photographs [2] or CCD/video cameras have demonstrated that 3D information can be extracted using motion [9] and stereoscopic techniques [4]. MIT city scanning project [5] developed a prototype system for reconstructing automatically textured geometric CAD models of urban environments using spherical mosaic images., where camera's position and orientation of each spherical image is first initialised using positioning sensors, then refined through image matching. The difficulties in reliable stereo matching, distortion from limited resolution and unstable geometry of CCD cameras are the major obstacles to reconstruct a 3D model of complicated environment with necessary accuracy and robustness. On the other hand, reconstructing 3D objects using range sensors has concentrated on reconstructing small objects such as teeth, bust, mechanical parts, etc. [13]. With the development of eye-safe laser range scanners, reconstructing relatively large objects in urban environment using range data becomes technically feasible. Range images acquired by range sensor do not require specific computations to get depth from data.

According to the mounting platform, laser-scanning technology is divided into airborne laser scanning [12] and ground-based laser scanning [1, 6, 7]. Airborne scanning systems can cover wide areas and are effective for DEM (Digital Elevation Models) and DSM (Digital Surface Models) but give low spatial resolution. Ground based laser scanning is mainly applied to rebuild 3D city models and to collect local geographic information. The vehicles can give highly dense and more accurate maps, but only for the limited areas they can access.

Highly accurate positioning (localization) is one of the major issues that have to be discussed when mounting a laser range scanner on a mobile platform. Many research efforts have contributed on this topic [8]; several systems are based on the integration of GPS (Global Positioning System), INS (Inertial Navigation System). In these systems, the INS system, which outputs velocity and attitude, is implemented to update positioning data when

GPS signal is not available. This is a common problem if the outage of GPS data is long, causing the INS solution to drift. To solve this problem, the odometers data have been integrated with the INS system output. In [7] a laser scanner is used to help the GPS/INS in localization.

In our approach the laser is redirected to scan out a plane perpendicular to the forward driving direction [1] and GPS/INS/Odometers for vehicle localization [8], the number of freedom of the vehicle motion is six, and optionally can be reduced to three. By the combination of the scanner's head rotation and the vehicle's forward motion provides coverage of roads and buildings (surrounding area). The laser scanner is mounted on the back of the vehicle, see fig. 1. The localization accuracy is less than 0.15 meter; the vehicle has been driven at speed 10-40 km/h. This means that the distance between two successive scanned laser profiles is about 0.25 to 1 meter.

There are various techniques of 3D construction from clouds of points for urban zones by laser scanner. In [11] the 3D models are built from range data using a volumetric set intersection method, others in [6] use laser scanners and line cameras, urban features like buildings, ground surface and trees are extracted in a hierarchical way.

The whole application was integrated in the vehicle using ^{RT}MAPS real-time software platform [3].

Figure 1. The instrumented vehicle and laser scanner

II. System Configuration

Figure 2 shows a block diagram with the main components of the system. The IBEO Laser scanner "LD A AF" is used for the scanning; this time of flight sensor can return the range from targets up to 200 meters for reflecting targets and up to 40m for dark targets with 1cm to 5cm accuracy. The scanning angle is 270°, and the angular resolution is 0.25° at a 10Hz scanning rate, this means that we have 10800 samples per second. The laser scanner can also provide intensity information about the reflected beam.

For vehicle localization, the state estimator is a processing module, which combines data from GPS, IMU and odometers using Kalman filtering. The outputs of the state estimator are the position and velocity of the vehicle at 85Hz. A Trimble DGPS receiver is used; it offers absolute positioning in a world-fixed reference frame at 10 Hz, with an accuracy of 1m. Data latency ranges between 30ms. and 150ms. as we described in [8].

The Inertial Measurement Unit of crossbow comprises of three accelerometers, three gyros, and sends 85 measurements per second. The wheel encoders provide forward speed with an accuracy of 0.5 m/s at 10 Hz. The encoders are mounted on the two back wheels. The resolution of one encoder is 32 pulses per revolution.

The data logger PC has a motherboard with two 750MHz Pentium II processors, and different types of acquisition cards. It is used to perform real-time calculation and filtering of the acquired data.

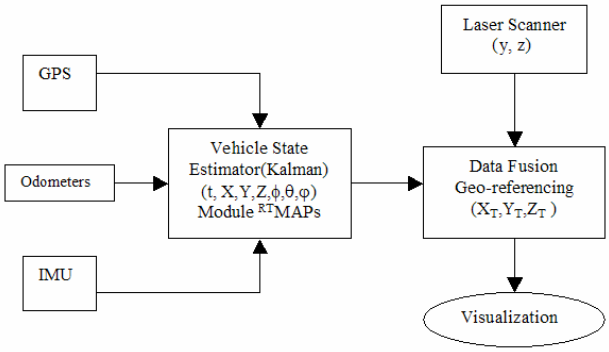

Figure 2. Block diagram of the main components of the system.

III. The Measurement Process

The goal of the measurement process is to convert laser measurements of a target point P_T into 3D coordinates in an Earth fixed reference frame or Mapping Coordinate Frame P_T^{Nav}. The following steps describe the kinematics calculations required for coordinates transformation, fig. 3:

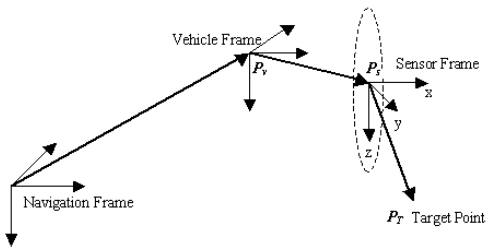

Figure 3. The geometry of the measurement process. (Geo-referencing)

1) The first step is to calculate the coordinates of the target point in the laser scanner sensor frame $P_T^{Scanner}$. The plane in which the laser scans, defines the Y-Z plane of the sensor frame. The scan angle, θ_s and the distance to the target r_s are returned by the laser scanner.

2) A rigid transform (translation and rotation) is required to locate the laser scanner (sensor frame) in the vehicle frame. The translational and rotational offsets P_s^v, and $\Re_{Scanner}^{Veh}$ are constant and were determined through a hand-eye typical calibration. If there is no rotation between the sensor frame and the vehicle frame, this means $\Re_{Scanner}^{Veh}$ is a unity matrix. And if we assume that the origin

of the vehicle frame and the sensor frame are the same, then P_s^{Veh} will be a zero vector.

3) The state estimator using Kalman filter is used to integrate the GPS/INS/Odometers and provides the position P_v^{Nav} and attitude of the vehicle. The origin of the vehicle frame is located between the two-rear wheels axis, and the NED (North, East, Down) is the used navigation coordinates system. The attitude data is used to calculate $\Re_{Veh}^{Nav}$, a 3x3 rotation matrix that transforms points from the vehicle frame to the navigation frame.

4) Using these definitions, the coordinates of the target in the navigation frame can be computed by:

$$P_T^{Nav} = \Re_{Veh}^{Nav}\Re_{Scanner}^{Veh} \cdot P_T^{Scanner} + \Re_{Veh}^{Nav} \cdot P_s^{Veh} + P_v^{Nav} \quad (1)$$

This configuration provides all the information needed to recover the 3-D structure of scanned surfaces. Unfortunately, errors affect each step of the measurement process and corrupt the final 3-D map. Reducing these errors is critical to achieve highly accurate results. The small errors in the vehicle position P_v^{Nav} prediction, sensor translation P_s^{Veh}, or laser range measurement r_s, result in an error on target position P_T^{Nav}. On the other hand, a 1 degree angular error in attitude estimation $\Re_{Veh}^{Nav}$, sensor orientation $\Re_{Scanner}^{Veh}$, or scanning angle θ_s produces an equally large error in the expected direction of the laser beam, resulting in an error of more than one meter at 60 m range. This motivates the attempt to remove as many sources of angular errors as possible. Two fundamental sources of angular error in our system: errors due to incorrect scanning geometry, and errors due to the inaccurate model of vehicle motion. The first source is reduced by a careful calibration, and the second is reduced by synchronizing the various data sources and interpolating between measurements, and by data fusion and estimation using digital filtering.

Figure 4 shows the result of the scanned area using the presented system; it presents the façade of "Ecole des Mines de Paris". This image is a bird view of the 3D reconstructed model as returned by our system.

This image contains approximately 1 million points representing only 1.5 minutes of the whole trajectory. The distance between two profiles is about 0.25 to 1 meter and the distance between two points in the same profile is depending on the target point range. We can extract the road surface, and another features like trees, bus stop, pedestrian, and vehicles.

The implemented onboard software can register and visualise the cumulative 3D model (cloud of points) during navigation. Another test track (Giat track, fig. 5) has been conducted with a longer trajectory (more than 3 km long). The total duration of the test is about ten minutes; there is more than 7.5 million points in this range image. There is an accumulative error of approximately 2 meters. Hence we can notice that the initial position and the final one do not coincide.

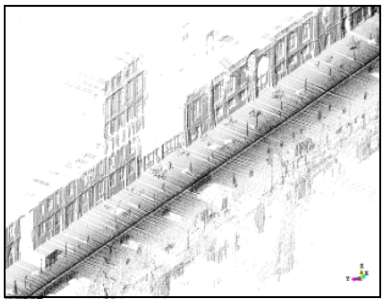

Figure 4. "Hôtel Vendôme" (Ecole des Mines de Paris) range points.

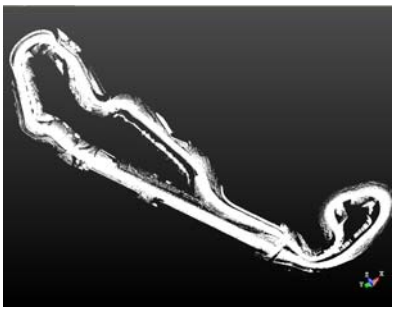

Figure 5. Top view of the reconstructed Giat test track

IV. SEGMENTATION

The segmentation is applied to the cloud of points in order to isolate the existing objects in the scene and to identify the nature of each object starting from definite structural features.

In the first time, the identification is limited to three types of objects, the most widespread objects in an urban environment, the road; the facades; and the trees.

A. *Enter-profiles Segmentation*

Our algorithm of segmentation uses general knowledge on the urban scenes, like the horizontal nature of the roads, the verticality of the facade and the free shape of the trees (classified as scattered points). This algorithm acts on each profile and separates all the points belong to each 3D object from the scene in an object class. Separation is made starting from an analysis by two histograms according to elevation (Z) and the longitudinal direction (Y) in one profile.

The road is the only horizontal (approx.) object in the scene. Road surface being the nearest object compared to other objects like buildings and trees, the point density is also bigger due to higher across track scanning resolution. This characteristic will lead to a histogram with a peak corresponding to the elevation in the ground as we can notice it on fig. 6. Thus, we classify all the points which belong in the vicinity of this peak as being pertaining to the 3D object "Ground". The same algorithm applied to the remaining points in the profile and according to the longitudinal direction allows separating the other existing objects in the profile as we can note it on fig. 7.

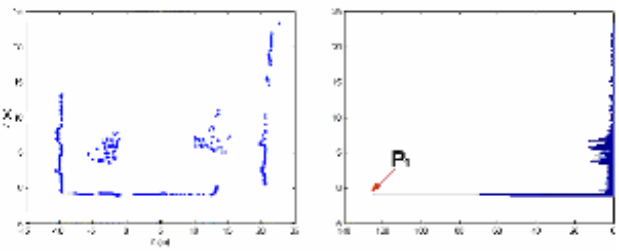

Figure 6. One profile with histogram on Z

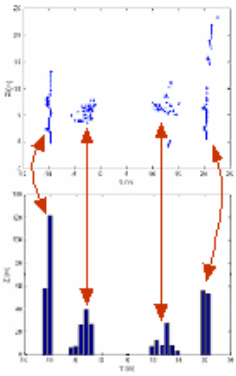

Figure 7. Objects profiles isolation using histogram on Y

B. *Pre-labeling*

This separation of profiles does not carry any knowledge on the nature of the objects to which these points belong (except for the road which is only extracted starting from histogram Z). Indeed, it is sometimes difficult even for human to distinguish nature of the objects starting from an irregular sampling from one profile for this object. However, some of these profiles of objects carry features which make it possible to decide within which class they are belong. For example, one profile of objects which has the variation on the histogram Y smaller than a given threshold, i.e. $y_{max} - y_{min} \leq th_1$, this object probably forms part of a facade. While an object which has the variation on the histogram Y larger than a threshold, i.e. $y_{max} - y_{min} \geq th_2$, is belonged to a tree. All the others profiles of objects which do not satisfy any of these two criteria are classified in a class of doubt. This stage of pre-labeling will be useful thereafter for the final labeling of 3D the objects.

C. *3D Objets Formation*

The formation of the 3D objects of the urban scene is done by regrouping of profiles that pertaining to the same 3D object. This regrouping must be made in an automatic way and according to a criterion of correspondence. Indeed, the most probable is to add one profile to the nearest 3D object. An estimate of this proximity is done by the calculation of the Euclidean distance between the centre of the added profile and the last profile of all the already existing objects in the scene, if the smallest of the distances lower than a given threshold (this threshold is a relation of the distance from the vehicle and the presence of zones of occlusions) we add it to the object which represents this minimal distance, otherwise this profile forms the core of a new object whose existence will be strengthened or not by next acquisitions. With each addition of a profile of object, the total segmented scene will be updated. The result of our segmentation algorithm is presented in fig. 8. The total cloud of points is represented in the middle and it is surrounded by the identified and separated objects.

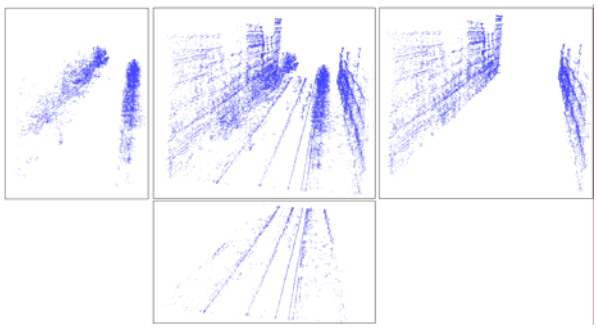

Figure 8. The trees, the facades and the road from Saint Michel acquisition

D. *Labeling*

The recognition of the semantic nature of the 3D objects is done from the pre-labeling already carried out at the level of each profile of object. Indeed we calculate the probability of membership of the object to each class of data according to the number of profile pertaining to each class. This means calculating:

$$P(X \in C_j) = \frac{nb\ de\ profils \in C_j}{n} \qquad (2)$$

Where, n is the number of profiles constituting the object in question and C_j is one of the three classes {tree, facades, others}; thus we obtain the probability of membership of each class instead of a rough threshold which determines the nature of each object.

V. DECIMATION AND 3D RECONSTRUCTION

The reconstruction technique depends on the application which uses the segmented data. Our reconstruction is a simple visualization of the urban scene by representative geometrical models for each object.

The decimation is a significant stage to reduce the number of points - where it is necessary - and to reduce any secondary treatment of data. Polygonal approximation method [10] is used to apply the decimation. This algorithm is rather simple and traditional; it models an object by a succession of straight segments. The number of segments is a function of the precision required by the model. The use of this algorithm in our case is adequate since it makes it possible to model the linear objects like the road and the facade by a limited number of points. Moreover, this algorithm is very useful in the detection of the roadsides presented in the following section.

A. *Road Edges (Borders) Detection*

The extraction of the ground corresponds to the extraction of the points belong to a horizontal and linear object. This definition makes it possible to classify at the

same time the points of the roadway and the pavement in the same class "Ground". The separation of these two different objects is done by using the polygonal approximation method applied to each object profile pertaining on the ground. It makes it possible to represent the roadway with an average error smaller than 5 cm and a maximum error lower than 10 cm by three points: the two edges and a point in the middle of the road. The two edges correspond to points where there is a variation of orientation with its vicinity in the same profile, the point in the middle makes it possible to preserve a representation of the convex form and not flat of the roadway. By repeating the process on the next profiles, we can follow these edges making it possible to detect the roadsides in the profiles where there are not objects which prevent a direct line of sight between the edges and the laser scanner.

B. *Objects Model*

To represent each identifiable object, we propose an adequate model.

- The road is the result of the triangulation of edges with the middle. A profile of the road is thus modelled by two straight segments connecting the middle point to the points of the edges. See fig. 9.
- The facades are plane objects, they are represented by their including envelopes.
- The trees are represented a simple geometrical primitive: an association of sphere to represent the foliage and a cone to represent the trunk. This model is parameterized by the dimensions of cloud of points of each object declared as a tree.
- The objects belong to a class of rejection are represented by a cube of side equal to the average of the variation along the three axes.

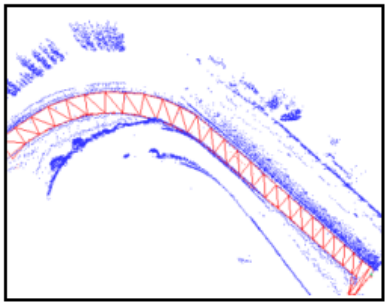

Figure 9. Road Surface extraction

Figure 10 gives an example of cloud of points, in comparison with the suggested model. More complex models can be proposed for precise applications.

VI. ROAD PARAMETERS EXTRACTION

This application uses our segmentation algorithm to isolate the road, to detect the two edges and to extract features of the road to be used in automobile driving assistance.

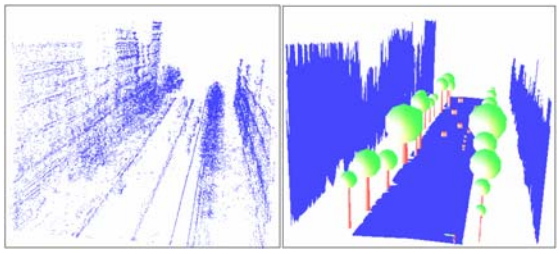

Figure 10. Cloud of points (left), proposed model (right)

Figure 11 shows the result of our segmentation algorithm on the totality of the track in comparison with the two edges measured by a more sophisticated way; a centimetric GPS which gives the coordinates of the two extreme white lines of the road with a high degree of accuracy.

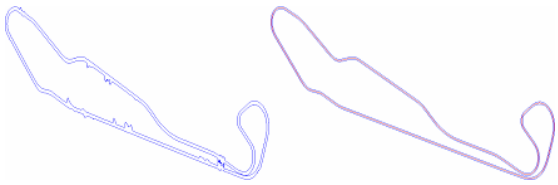

Figure 11. The segmented bords (left), the measured bords by a centimetric GPS (right)

A. *Road Width*

The road width is regarded as the distance between the two segmented edges in the same profile. Figure 12 represents a comparison between the width of the physical (real) road and the distance between the two white lines.

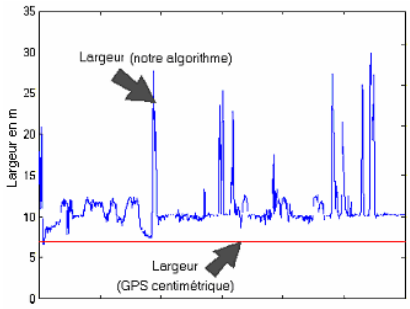

Figure 12. Road width

We can notice that there is a difference of three meters between the two widths presented. This difference can be interpreted by the margin of the asphalt of about a meter and half on each side of the road.

The small peaks that exceed the physical width present a correlation with the increase in the road curvature; see fig. 13. Indeed, on the turns, the width of the road is larger to ensure a larger speed limit of skid.

The large peaks correspond to the detections of intersections road. On the intersections, the physical roads limits do not exist and consequently the width presents these peaks of more than ten meters of amplitude. Figure 14 gives an example of this false detection of the edges with an image representing the truth ground. This photo shows

the exit points of the road at the same places where the algorithm does not succeed to detect the edges.

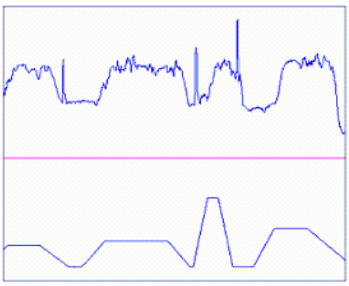

Figure 13. Small peaks in road with and carvature correlation

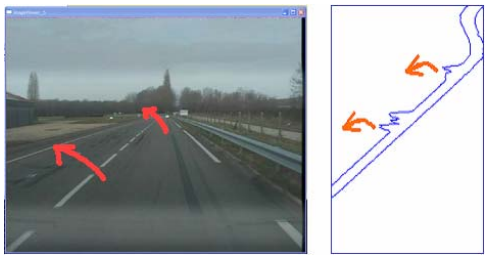

Figure 14. The intersections roads

This algorithm can then be used as a detector of roads intersections which constitutes a significant source of risk during automobile driving.

B. The Curvature

The second extracted parameter is the curvature of the road. It is a significant factor for the calculation of the maximum speed of skid. We model the segmented edges by pieces with third degree function and then we calculate analytically the curvature on this model function.

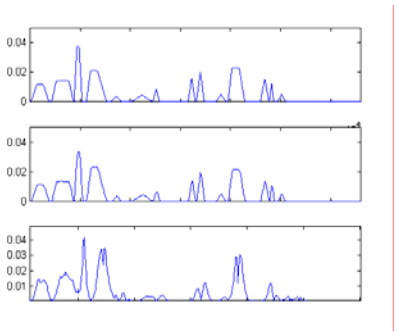

Figure 15. Theorical curvature (top), our algorithm on the centimetric GPS data (middle), our algorithme on the segmented boarders (down)

Figure 15 shows in top the curvature delivered by the GPS measurement, the second one is the curvature calculated by our method on the edges measured by centimetric GPS and the last one is the curvature starting from the segmented edges. We can notice the correlation in the form and the values of the curvature in the three cases. This proves the robustness of our method of calculation of the curvature and the validity of our algorithm of segmentation of the roadsides.

VII. Conclusion and Future Studies

The goal of this research is to develop a system which is capable of acquiring data in three dimensions. To build an accurate 3D model of urban outdoor environment, a vehicle-borne laser range scanner coupled with a GPS/INS/odometer based navigation system was developed. The system operates in real time and builds high-resolution maps of static environments around the vehicle. We presented our approach for segmentation of urban scenes in real time starting from clouds of points acquired by the system. Three types of classes are identified, the road, the façade and the trees. Some road parameters are extracted.

The next work will concentrate on a careful study of the system to determine its actual accuracy and to minimise the measurement error. We are currently working on the extraction of other classes like stationary vehicles, etc. Also we will focus on filtering the moving (dynamic) obstacles around the vehicle. We are also working on texture mapping using a linear or a CCD camera for realistic and VR applications.

References

[1] I. Abuhadrous, F. Nashashibi, C. Laurgeau, F. Goulette "Onboard Real-time system for Digitizing and Geo-referencing of 3D Urban Environments". In Proc. of the 11th International Conference on Advanced Robotics. June 30th – July 3rd , 2003, University of Coimbra, Portugal.

[2] El-Hakim S. F., C. Brenner, G. Roth, “A multi-sensor approach to creating accurate virtual environments”. ISPRS Journal of Photogrammetry & Remote Sensing, vol. 53 (1998) 379–391.

[3] F. Nashashibi, B. Steux, P. Coulombeau, C. Laurgeau, "RTMAPS a framework for prototyping automotive multi-sensor applications". In Proc. of the IEEE Intelligent Vehicles Symposium 2000. Dearborn, MI, USA, October 3-5, 2000.

[4] Grau, O., "3-D Modeling of Buildings using High-Level Knowledge", Proc. of Computer Graphics International 1998 (CGI'98). June 22nd - 26th, 1998, Hannover, Germany.

[5] http://city.lcs.mit.edu//city.html, MIT City Scanning Project: Fully Automated Acquisition in Urban Areas.

[6] H. Zhao, R. Shibasaki, "Reconstructing Textured CAD Model of Urban Environment using Vehicle-borne Laser Range Scanners and Line Cameras", Proc. of International Workshop on Computer Vision Systems, Jul 2001 Vancouver.

[7] H. Zhao, R. Shibasaki, “High Accurate Positioning and Mapping in urban area using laser range scanner”. IV2001, 13- 17 May, 2001.

[8] I. Abuhadrous, F. Nashashibi, C. Laurgeau. "3-D Land Vehicle Localization: a Real-time Multi-Sensor Data Fusion Approach using RTMAPS ". In Proc. of the 11th International Conference on Advanced Robotics. June 30th – July 3rd, 2003, University of Coimbra, Portugal.

[9] S. Thrun, W. Burgard, and D. Fox. “A real-time algorithm for mobile robot mapping with applications to multi-robot and 3D mapping”, ICRA-2000.

[10] V. Ramer, “An Iterative Procedure for the Polygonal Approximation of Plane Curves”, Computer Vision Graphics and Image Processing, 1(3) : 244-246, 1972.

[11] Stamos I., P.K. Allen, "3D Model Construction using range and Image data ".CVPR 2000.

[12] http://www.eurosense.com

[13] H. Shum, K. Ikeuchi, and R. Reddy, "Virtual reality modeling from a sequence of range images," IEEE / RJS International Conference on Intelligent Robots and Systems. 1, Sept 1994, pp. 703-710.