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Tracking objects using a laser scanner in driving situation based on modeling target shape

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Abstract— **In this paper, we present a new approach to solve the problem of tracking partially hidden objects by a single layer laser scanner. Taking into consideration the shape of the detected object, we have optimized the clustering and the estimation of results. We propose to adapt the detection according to the predicted pose and the occlusions. We have developed an algorithm to detect the security barriers of the road in some conditions. Finally, we have projected our interpretation in the image of a vision system to provide the area of interest to be analyzed and fused with our results. This method is experimented using a single layer laser scanner of type SICK mounted on a vehicle and validated by the means of video data.**

I. Introduction

"Advances Driver Assistance System" (ADAS) integration is a way to improve safety and comfort in a vehicle. In order to make the assistance more efficient, ADAS system needs context information about the driving situation. Sometimes, context information, like the vehicle speed, is enough to define the domain of action of the ADAS. However, a lot of complex ADAS systems need more information about the driving situation: description of the surrounding environment, position of the vehicle on the lane, localization on a digital map, etc... Surrounding objects detection and tracking are a part of the context data retrieval, and it is a challenge because the road environment is complex, dynamic and variable.

Recent projects on pedestrian detection [1] or obstacle detection [2] have highlighted the use of multi-sensor data fusion and more generally the multiplication of data sources in order to obtain more reliable, complete and precise data. The Vehicle to Vehicle communication is an example to enlarge the field of view of a vehicle [3].

However, it is necessary to explore the whole capability of sensors in order to benefit of all available data for data fusion. This paper describes an object detector and tracker based on laser scanner sensor data and is dedicated to be integrated in multi sensor system.

II. Related works

Since the dynamic conditions, like detecting moving objects and tracking methods, have been developed using exteroceptive sensors such as video cameras, radars and laser range scanners (LIDAR) and sometimes combined with internal sensors.

A lot of work deals with vision based systems using stereo vision to obtain the 3D estimation of the detected object [4] [5], due to the restricted lighting conditions for offering good performances of vision processing, the large field of view and the good resolution of the LIDAR sensor. Some systems are based on multi-sensor fusion tacking the advantage of the complementarily of the images coming from camera and range data coming from radar or LIDAR sensor [6] [7].

In, these last years, a lot of work is developed to process only the range data in order to detect track and recognize different objects in a driving scene. Ref. [8] proposes a method to cluster LIDAR data and classifies the detected objects (vehicle or pedestrian). These approaches are tested on an autonomous vehicle like Cybercar [9]. Ref. [10] describes a classification method from a static sensor for monitoring and analyzing the traffic at intersection. Ref. [11] describes capabilities for classification of pedestrians and correct segmentation of objects in the presence of occlusion, but it gives little implementation details. Ref. [12] proposes a method analyzing the shape of the detected vehicles. The results are then utilized by a collision warning system.

The next sections describe one of our approaches to obtain data about context driving situation. Such as in [10] [12], we take into account the shape of the detected object to have better precision in clustering and estimating. We propose to adapt the detection according to the predicted pose and occlusions. The dimensions of the object are filtered in order to tackle the scan effects. The track and the dynamic estimation are achieved with a classical Kalman filter and data association is applied on segmented data. The results are bounded boxes which can be used by the image processor to classify the objects. This method is experimented using a single layer laser scanner of type SICK mounted on a vehicle and validated by the means of video data.

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III. Modeling Target Shape

A. Laser Scanner

Laser Scanner is an optical remote sensing technology, which measures the properties of scattered light, to find range and/or other information of a distant target. The prevalent method to determine distance or surface to an object is to use laser pulses, like the similar radar technology, which uses radio waves instead of light. The range to an object is determined by measuring the time delay between transmission of a pulse and detection of the reflected signal. The rotating mirror allows the same transmitter/receiver to scan the zone of interest with an angle up to 360°.

Laser Scanners are characterized by their scan frequency (maximum scanning speed), horizontal angle (maximum scanning angle), range (maximum measurement distance), resolution (minimum angle between two consecutive measurements) and number of layers (number of simultaneous scanning planes).

We're dividing the scanning plan into four areas: (Fig.1)

- "Out of Range" area: defined by the scanner range
- "Out of View" area: defined by its horizontal angle
- "Hidden" area: defined by the objects present in the visible area
- "Visible" area: limited by the previous three areas. Laser scanner can only give information about objects present in this area

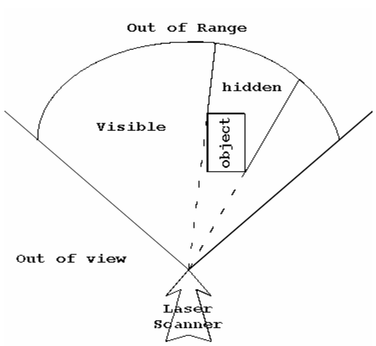

Fig.1. The scanning plan of a Laser Scanner can be divided into four areas defined by its range, scanning angle and the objects presents in the visible area.

We're not working with occupancy grid as in [13], but we're dividing the scanning plan into these areas to solve the problem of the partially hidden objects.

B. Object Characteristics

In its visible area, a laser scanner can detect all objects with sufficient reflectivity of the laser beam. Some objects can be detected as static (such as stopped vehicles, trees, traffic signs…), or dynamic (such as moving vehicles, pedestrians, bikes…). But other objects such as security barriers appear to have zero relative speed independent of the detector velocity. These objects are identified by special algorithms in the next paragraph.

Our approach is to represent an object by the smallest parallelepiped shape that can contain it. Knowing the direction of a vehicle is important, but our representation is generalized for all types of objects and we can't define the direction of non- regular shaped - objects, so the parallelepipeds shapes are supposed to be horizontal and parallel to the "x" axis of the laser scanner (Fig.1).

The laser scanner is a 2D sensor. If it's used horizontally, it can detect the length and width of an object, but it can't give any information about its height. The classification of objects, according to their dimension, position and movement, can give a prediction of their height.

Other sensors such as cameras can be used in complementary with the laser scanners. Vision system can analyze the area classified by the laser scanner data processor as occupied by an object to confirm its existence [14] and to recognize its type and dimensions. The data fusion can be at higher level; the vision system can run an object tracking algorithm [13], and the obtained tracks can be fused with the laser scanner trackers results.

IV. Detecting Road Limits

In good visibility conditions, the vision system can detect the road limits (security barriers, white lines…). This detection helps in the clustering of laser scanner data to remove unused objects before sending data to the tracking algorithm. If the vision system failed, we have to find another source of information to avoid unnecessary tracking of off-road objects.

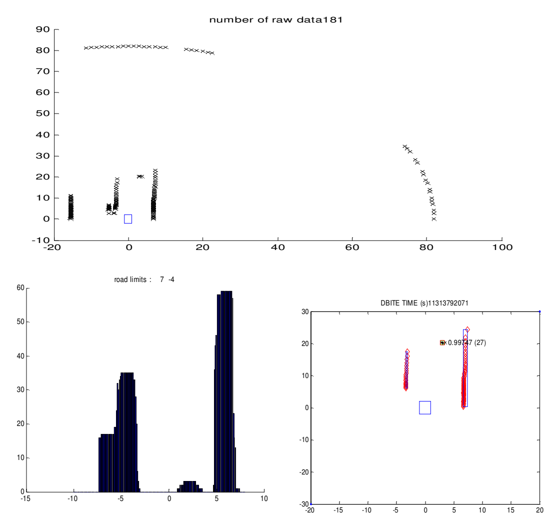

Fig.2. Raw data selection for object on road detection with laser scanner. a) Laser scanner data from a sensor embedded in front of the vehicle (blue box). b) Number of data for each 10cm on axis x. This histogram allows the road limits detection when the road is limited by vertical structure. c) Only raw data in interest area is kept. The red dots are affected to road limit and the all data out this zone are removed.

We propose the use of the laser scanner data to detect, if possible in some cases, the road limits. In [15], the used

LIDAR has the ability to give information about the reflectivity of the detected objects; this helps to detect the lane marks. But because we're using a standard one layer laser scanner, we have developed an algorithm to detect the security barriers, by analyzing the intensity of the vertical projection of the laser scanner data (Fig.2.). If the security barriers exist and are visible to the laser scanner, we will get information to be fused with the vision system, only if it can detect the road limits and to be used alone.

V. Hidden Objects Problem

The laser scanner can detect one or two sides of a vehicle depending on its position, but the detected points are not uniformly distributed on these sides. So using the center of gravity of these points can introduce an unacceptable error and discontinuity. We can approximate the center of gravity of an object by the geometrical center, so the problem is how to get this point with precision.

A. *Reconstructing Totally Visible Objects*

After the filtering and the clustering stages, we get a set of points describing the object form from the point of view of the laser scanner. This form can be one noisy segment, if the laser scanner can only see one side of a vehicle. If it detects two sides, the laser scanner can detect two perpendicular noisy segments ("L" shape) or an unknown form, if the object has no defined form.

In all cases, we have to reconstruct the original form of an object in order to calculate its dimensions and the positions of its center of gravity or geometrical center. We suppose all objects to be symmetrical, and their half is detected, if they are totally visible. The problem of detecting one side of an object (as one segment) will not be solved before collecting more data about the object. So to reconstruct the object, we add to the detected points their symmetry; the centre of symmetry is supposed to be the medium of the segment joining the first to the last point of the cluster. We have now a first approximation of the object form and its geometrical center. This approximation will be updated after each scanning according to the collected data and the object position.

B. *Reconstructing Hidden Parts of an Object*

The detected object can be partially hidden in one of the invisible areas (Fig.1.): the out of view area, the out of range area or the hidden area. The recognition of any hidden part of the object is based on the position of the object in the visible area and the position of other objects that can be present in the scene (Fig.3.). Theoretically, all objects with supposed rectangular shapes (such as vehicles) are detected as two perpendicular segments (or “L” shape), if they are totally to the left or totally to the right of the laser scanner horizontal axe “x” (Fig.3.); otherwise, they will be detected as single segment.

To localize the four corners of a vehicle, in order to get its dimensions and position, we combine the information having less error with the data history collected for the vehicle. If an object is detected for the first time (no history), the measured position and dimensions will initialize its state, and they will be the history of the next scan. In the example of (Fig.3.), the five vehicles are localized and measured in this way:

- V1: the corners “c” and “d” are supposed to be detected, so we have the position and the width of the vehicle but not the length, so “a” and “b” are taken from the history of V1
- V2: only the corner “c” is supposed to be detected, so we have the position but not the dimensions, “a”, ”b” and “d” are taken from the history
- V3: the corners “a”, “d” and “c” are supposed to be detected, so we have all information about the vehicle position and dimensions because we suppose it as symmetrical
- V4: only the corner “a” is supposed to be detected, so we have the position but not the dimensions, “b”, ”c” and “d” are taken from the history
- V5: near the out of range area, the corners “a” and “c” can be detected, but practically at high distance the detection error is very high, so only corner “d” is supposed to be detected and the position of the others are calculated from the history data

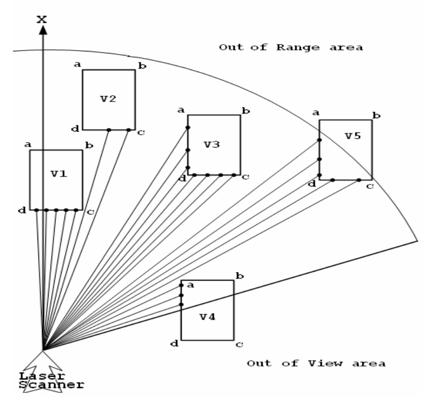

Fig.3. the vehicle V1 is visible as one segment and V3 as two perpendicular segments; V2 is partially hidden by V1, and V5 is partially hidden in the out of range area and V4 is partially hidden in the out of view area.

These are five typical situations; the algorithm takes also into consideration combined situations such as vehicles having a part hidden in the out of view area and another part hidden by another vehicle.

On the detected object, the distance between two consecutive points is smaller if the object is closer to the laser scanner, so the error in dimension measurement is bigger at high distances. In general, the signature of an object in the laser scanner image is more precise at low distances, and without taking into consideration the noise effect, the dimensions are bigger at low distances. The simplest way to be near the real dimensions is to save at each scanning the maximum between the current detected dimensions and the last saved dimensions.

Practically, some noise points are considered by the clustering algorithm to belong to the detected object. In this case, the detected dimensions can be bigger than the real dimensions, and they are saved and compared to the new dimensions in the next scanning. This will always give the big dimensions wrong information.

Our solution of this problem is to pass the calculated dimensions by a time filter instead of saving their maximum. This algorithm will be applied only to the measured dimensions of the object; the saved dimensions will always replace the unmeasured values.

C. Filtering Object Dimensions

The measured object dimensions are the length "L" and the width "W". As described in section III.B, at each scanning, we have the possibility to measure "L" and "W", the possibility to measure one of them and get the second from the history, or the possibility to get both from the history, if they can't be measured.

To solve the noise problem of measured dimensions, we propose to filter them by this fixed gain filter:

$$W_{k+1} = W_k + G\,(W_{meas} - W_k) \qquad (1)$$

$$L_{k+1} = L_k + G\,(L_{meas} - L_k) \qquad (2)$$

G is the filter gain ($0<G<1$), W_{k+1} and L_{k+1} are the filtered dimensions at time t_{k+1}, W_k and L_k are the filtered dimensions at time t_k, W_{meas} and L_{meas} are the measured dimensions at time t_{k+1}.

The determination of the correct gain is very important; if G is very low (near zero), the variation of the dimensions will be slow. This is good for noisy environment, but it makes the system adjust the detected objects' dimensions slowly: this is not suitable for high relative speed objects.

We calculated the gain based on these values: the maximum relative speed of a detected object is supposed 160 Km/h, the range of view of the laser scanner is 80 meters, and the scanning frequency is 75 Hz.

Let W_n be the filtered width at time t_n, W_0 be the initial detected width at time t_0, and W be the measured width, supposed fix, between t_0 and t_n.

From the equation (1) we can easily demonstrate that:

$$W_n = W_0(1-G)^n + GW\left[\sum_{i=0}^{n-1}(1-G)^i\right]$$

The sum is a geometrical series, then:

$$W_n = W_0(1-G)^n + GW\left[\frac{1-(1-G)^n}{1-(1-G)}\right]$$

so: $W_n = (W_0 - W)(1 - G)^n + W$ (3)

let: $p = W_n / W$, so we can calculate the filter gain G:

$$G = 1 - \sqrt[n]{\frac{(p-1)W}{W_0 - W}} \qquad (4)$$

If the vehicle is suddenly detected ($W_0=0$), we get the simple equation: $G = 1 - \sqrt[n]{(1-p)}$ (5)

G is now independent of W, and it can be the same for the Width W and the length L.

If we want from the filter to reach 99% of the dimensions ($p = 0.99$) of a suddenly detected vehicle in the horizon of the laser scanner (at 80 meters) before it can traverse 10% of the field of view, the number "n" of filter cycles is the number of scanning (at 75 Hz scanning frequency) and it should be less than 14 scans: from the equation (5) we can calculate the minimum gain to be used: $G = 0.298$

VI. Kalman Filter Tracking

A. Modeling Vehicle Dynamic State

The tracking phase is handled by classical Kalman filters: one filter per track with the same model for all tracks. The expression "All Models are Incorrect" is true but practically we're trying to use the less complicated model that describes the state of our targets with an acceptable error. The model formalization depends on the measured data types and the desired state estimation.

The laser scanner can only give the relative position of the detected targets; however, our experiment vehicle is equipped by many sensors to measure its state. This is necessary to get the absolute state of the detected objects.

The motion of the detected vehicle is supposed to be linear and uniform during two scans, so the dynamic of the vehicle in the horizontal plan of the laser scanner is described by the equations (6) and (7):

$$x_{k+1} = x_k + v_{xk}\,T_k \qquad (6)$$

$$y_{k+1} = y_k + v_{yk}\,T_k \qquad (7)$$

Where: (x_{k+1}, y_{k+1}) is the predicted position of the detected vehicle at time t_{k+1} knowing its state at time t_k, (v_{xk}, v_{yk}) represents the velocity of the detected vehicle at time t_k, and T_k is the sampling period at time t_k, this period hasn't to be constant and it can vary from scan to another. Using this model, the state vector and the state transition matrix are:

$$X_k = \begin{bmatrix} x_k \\ y_k \\ v_{xk} \\ v_{yk} \end{bmatrix} \quad \text{and} \quad A_k = \begin{bmatrix} 1 & 0 & T_k & 0 \\ 0 & 1 & 0 & T_k \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

With no inputs, the input matrix is null and the matrix C relating the state X_k to the measurement Y_k should be:

$$C = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{bmatrix}$$

The measurement error covariance R should be calculated from the laser scanner characteristics, and the model noise covariance Q_k should take into consideration all errors imported by the approximation of the real motion by the equation of the model.

B. Data association

For the association of the detected objects to the existing tracks, a lot of work has been developed [16] [17]. We're using the simple method of the nearest neighborhood based on the "Mahalanobis" distance which takes into consideration the track estimation error covariance. Associated tracks states are updated and unassociated tracks are predicted and not destroyed before a predefined time after their last update. Unassociated objects initialize new tracks.

We're working now on a method that applies the belief theory to calculate and update the confidence on tracks, based on the work of [18].

VII. Experimental Results

The demonstrator vehicle "STRADA" (Fig.4.) of the laboratory "Heudiasyc" is used for the experiments. It's equipped with a "SICK" laser scanner, running at 75 Hz, with a range of view of 80 meters and an angle resolution of 1 degree. A color video camera films the front view at a speed of 10 fps.

Special calibration procedure (not described in this article) is performed to calibrate the vision system's field of view to the laser scanner scanning plan. This calibration is necessary to project the laser scanner data and the interpretations in the captured image.

Fig.4. Demonstrator vehicle STRADA

In (Fig.5.), we can see four different situations: the laser scanner data and its interpretation by our algorithms in the left images, and the video images and the projection of the interpretations in 3D representation in the right images.

In the left images, the yellow lines represent the laser beams. The detected points on an object are the green points; the detected objects are represented by a red box and their estimated shape by the green box. We can also see their geometrical center, an identifier (integer) and their speed vector (red segment giving the direction and the amplitude of the velocity).

The green points of the left images are projected in the right video images, and the green box is projected in 3D representation with a fixed height of 1.5 meter to enclose a normal car.

In (Fig.5.a), a vehicle starts entering the field of view, with not enough data. It's represented by a narrow box. In (Fig.5.b), the vehicle becomes visible, and it's well enclosed in the green box. In (Fig.5.c), a new car appears and the first one becomes partially visible. But with the saved information, their dimensions are still known. In (Fig.5.d), the second vehicle becomes totally visible, and the first one is still in the field of view.

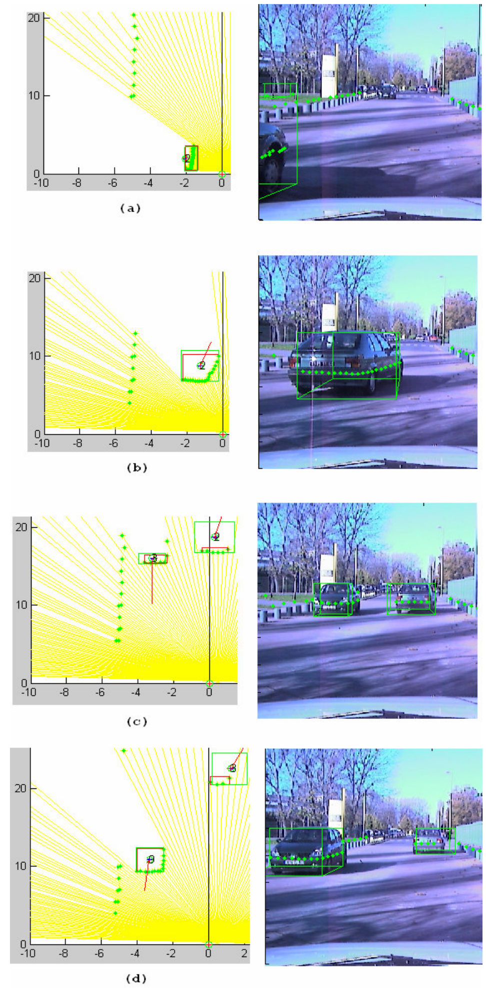

Fig.5. (a) a vehicle starts entering the field of view (b) complete vision of the vehicle by the laser scanner and the video cam: (c) a second vehicle not completely detected by the laser scanner (d) the dimension of the first vehicle are known even though it's not completely visible by the laser scanner.

The 3D boxes of the right images determine the zone of interest to be analyzed by the image processing algorithm. Depending of what type of image processing will be done,, the image processing tracking results can be fused with the laser scanner tracking results to get the final decision, or the vision system can do shape detection to classify the objects detected by the laser scanner.

In (Fig.6.a) we show the detection of pedestrians: collected pedestrians are detected as two blocks. (Fig.6.a) shows the detection of big objects such as buses because we can't detect the height of an object by the laser scanner. The default height is set to 1.5 meters.

The results of security barriers detection algorithm are shown in (Fig.7.). We're driving in a 2x2 lane road, where the security barriers can be detected by the laser scanner. We're only tracking the vehicle in our direction, (Fig.7.b) and we removed the detected security barriers and the vehicle in the other direction (Fig.7.a).

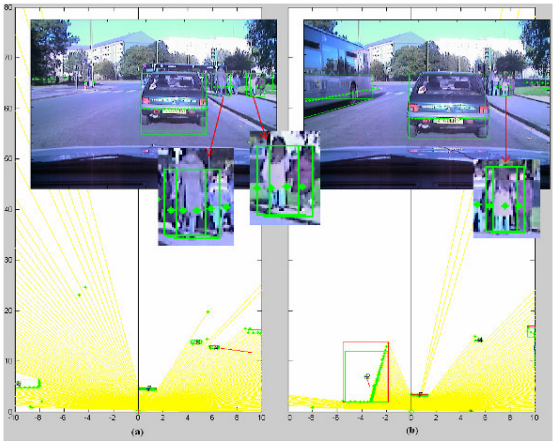

Fig.6. (a) pedestrians detection (b) Bus detection

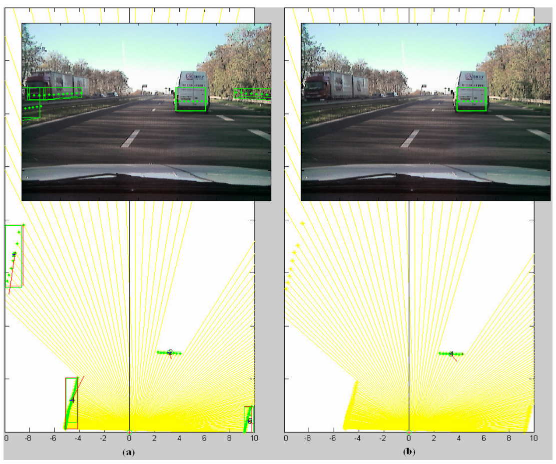

Fig.7. (a) before and (b) after removing security barriers and objects out of road borders

These first results are promising, and we hope to improve them by data fusion with vision system results.

VIII. CONCLUSION

In this paper we have described a new method to solve the problem of tracking partially hidden objects. To describe the different positions of partially hidden objects, we divided the scanning plan of a single layer laser scanner into visible area and invisible areas. The detected objects dimensions are filtered to solve the problem of noisy measurements, and the non- measured dimensions are read from the track's history. Detected objects are tracked by Kalman filters on one hand. On the other hand, we have developed an algorithm to detect the security barriers of the road in some conditions. Finally, we project our interpretation in the image of a vision system to give the area of interest to be analyzed and fused with our tracker results.

The future work concentrates on modeling the confidence in the detected objects and the update of the confidence by multi-sensor fusion, taking into consideration the temporal update and the occlusion problem.

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