OBJECT DETECTION WITH LASER SCANNERS FOR AUTOMOTIVE APPLICATIONS

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Abstract: Laser scanners are cost-effective, easy-to-use measurement devices which are suitable for applications in the automotive sector, e.g. collision avoidance and vehicle guidance. The LD A AF has long range, high resolution and high reliabilty for monitoring the surrounding area. The sensor contains a DSP-board for complete processing of the measured data, including an object detection algorithm. This algorithm tracks objects and calculates parameters like position, size, speed and acceleration. These objects are sent to the host computer. The algorithm is configurable for different conditions, e.g. indoor or outdoor tracking with low or high vehicle speeds. *Copyright © 2000 IFAC*

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1 INTRODUCTION

This paper describes the application of Laser Scanners for vehicle guidance and collision avoidance. The scanners used are 2d and quasi-3d Laser Scanners. They may be used for safety, comfort and guidance applications. The scanners have a wide opening angle of up to 270°, so they can be arranged to cover the complete area around the vehicle. No object (other vehicle, pedestrian) can approach without being seen by the scanners. Inside the scanners, the measured distances are processed by a simple DSP-based computer. From the measured distances, so-called „raw data", objects are built and then tracked as long as they re-appear in the subsequent scans. These objects are on-line reported to the vehicle guidance system via a CAN bus. Transmitted data includes size, position and velocity of the objects.

1.1 The LADAR DIGITAL A AF

Fig. 1 : LD A AF

The LD A AF is a member of the IBEO product line LADAR DIGITAL. Based on the standard laser scanner LD A, a new laser scanner with appropriate technical data were developed for the project "Autonomes Fahren". In addition to the improved technical data, the LD A AF has a built-in 32-bit DSP computer board for sensor-internal signal processing, thus eliminating the need for external computations.

Function principle The LD A AF is an active sensor and depends not on daylight or other light sources. The laser scanner actively emits pulses from an InGaAs laser diode in the near infrared and measures the incoming reflections of those pulses. The measurement principle is based on the time-of-flight method, where the distance to the target is directly proportional to the time between transmission and reception of a pulse.

The scanning of the measurement beam is achieved via a rotating prism and covers a viewing angle of 270°. The angular beam separation is 0,25°. With an optical beam divergence of 5 mrad (corresponding to a beam diameter of 50 cm in 100 m) the single measurements overlap each other. This overlap avoids gaps within the whole working range so even slim objects like poles will be detected. The scan frequency is 10 Hz. The laser scanner is eye-safe and fulfills the requirements of laser class 1.

The range of laser scanners depends on target size and reflectivity. The distance range of the LD A AF covers the near field beginning at the lens up to 150 m on reflector targets. For dark targets with a reflectivity of 5 % the range is approx. 40 m. The standard deviation of a single measurement data is about 3 cm (1 sigma).

1.2 Built-in signal processing

The measurement control is done by a 16 bit microcontroller. The distances and corresponding angles are measured simultaneously in order to get a 2D range profile. The angle measurement is done by a high resolution angle encoder. A second microcontroller transmits the complete 2D range profiles via a high-speed transputer link interface to the DSP computer board.
This computer board was developed by IBEO and uses a TMS320C32 digital signal processor with two transputer link interfaces and one CAN interface. One link interface is used to read the range profiles from the measurement unit. The second link interface is free for external user-specific applications like visualisation of the 2D range profiles.
The used CAN interface is running with a speed of 1 MBit/s and supports both CAN Specification 2.0 A and B.

2 THE SOFTWARE: OBJECT TRACKING

2.1 Goals and expectations

A vehicle guidance system is usually not interested in details of the surroundings, but needs a precise and reliable list of obstacles around the vehicle. For those applications, the built-in DSP board reads the raw data generated by the sensor and performs the object tracking. In a first step, the objects are extracted from the raw data by isolating clusters of measured distances which are believed to belong to one object. These objects, called „segments", have static attributes like size and position. Then, in the second step, the objects are compared to the objects of the previous scan, thus finding the identical objects and tracking them through subsequent scans. Since their movement is then known, dynamic parameters like velocity and acceleration is now calculated. This dynamic data is fitted into a Kalman filter to predict object movement and thereby further enhance the detection quality.
The processes used for object tracking may be configured by a number of parameters. The system is expected to report all obstacles which lie within the detection area of the scanners with the high accuracy and reliability made possible by the scanner hardware.

2.2 Object detection

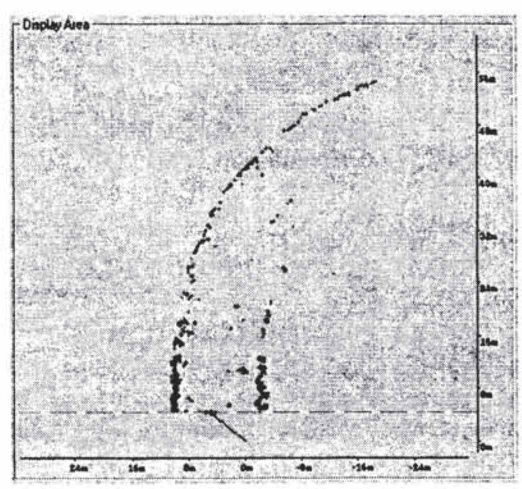

Fig. 2: Raw scan data of a street scene with a right turn

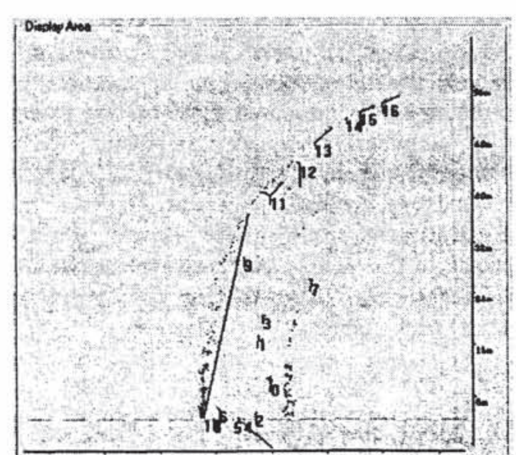

Fig. 3 : The same scene as Fig. 2, but with objects. The shown number is the object number, object 0 was sent first.

The first step of the object tracking process is to isolate the objects in the raw data. This is done by converting the angle and distance information into a x-y-coordinate system. Then, scanpoints which are close together are assigned to the same object, thus transforming a set of scattered data into point clusters, the segments. Attributes are then calculated for all segments to allow the assignment of segments to the objects of the previous scan. Since only the current scan is used in this first step, those attributes are static and include length and width of the segement, the number of scanpoints and the center (an artificial attribute built by calculating the mean value of all coordinates). Furthermore, the leftmost, rightmost and nearest points of each segment are used as attributes.

2.3 *Object tracking*

In the second step, the segments found in the scan data are assigned to the objects already tracked by the sensor. By tracking objects through subsequent scans, dynamic parameters like speed and acceleration can be accurately calculated.

Kalman filter All objects from the previous scan are run through a Kalman filter to estimate their expected position in the current scan. This estimated position is then used later to assign the new segments to the objects.

The dynamic parameters of a new object are unknown and are set to default values. These values are depending on the application: In a static application, where the sensor is used to monitor pedestrians moving on a sidewalk, only low initial speeds are needed because the objects to be tracked will not move far from scan to scan. A sensor mounted at the front of a car needs greater longitudinal velocity, assuming the car's primary movement is straight ahead. Ideally those values are calculated from the vehicles velocity, if it is known.

The result of the Kalman filter, besides the position estimation, is a parameter indicating the quality of the estimation. If the quality becomes too low, because, e.g., the object was tracked for some scans without assigned segment, the position estimation is unreliable and the object is deleted from the object list.

Assigning segments to objects After startup or if no objects were visible, the object list is empty. Segments are then added to the object list as new objects with the dynamic parameters of the new objects set to default values.

If there are objects in the object list, each object is assigned its closest segment, „closest" being a defined relation considering sizes and positions. Several cases can happen here:

- A segment is closest to more than one object. In this case, the segment is assigned to its closest object, the other object(s) don't have an assigned segment.
- More than one segment is closest to one object. If the combination criteria are met, the segments are combined to a bigger object, or the object may have split into two separate objects.
- There is no segment close to an object. The object can now be tracked as a „ghost object" or be discarded. This case happens when objects are hidden from the scanner by another object in the line of vision, or if they get out of range.
- There is no object close to a segment. The segment can be added to the object list as a new object.

After the segment-to-object-assignment is complete, some simplifications are done. „Ghost objects" without assigned segment can be eliminated if they have not been tracked long enough for the dynamic parameters to become stable since tracking objects with only its default values makes little sense. Keeping those objects in the object list would only slow the calculations since the predicted position will be unreliable.

Sorting of the output list The result of the object tracking is a list of objects seen by the sensor. Typically, not all of those objects are sent to the vehicle control because the CAN bus capacity is limited. Even if all objects are sent, it makes sense to send the „best" object first to allow a faster reaction to critical situations. There are several criteria for the „best" object between which the user may choose to decide which is suitable for the application:

- Radial distance. The closest object is sent first. This is suitable for static or low-speed applications. When driving with a higher speed, relevant objects ahead of the vehicle may be reported too late. As distance, the closest distance to the object is used.
- Look-ahead. The user can choose a position, typically in front of the vehicle, which marks the „best" position. Objects further away from this position get a lower ranking, except if they are closer to the sensor.

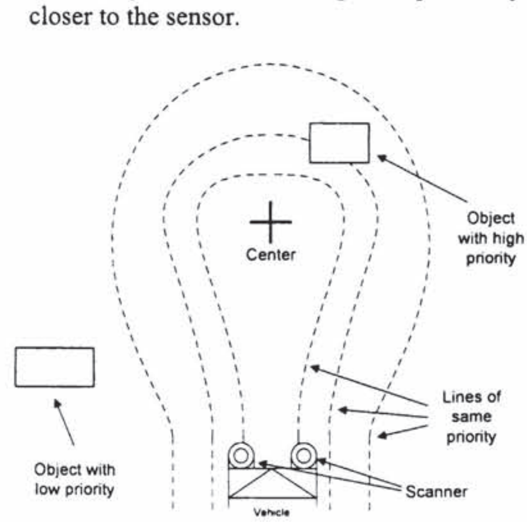

Fig. 4: The look-ahead criterion

This criterion is suitable for fast movement.

- Radial velocity. The fastest object which approaches the sensor is the „best" object. This criterion may be used to implement an external time-to-collision criterion.
- Radial-time-to-collision. The radial object speed is divided by the range to the object, so that closer objects may have a higher priority than fast objects which are far away. This is a simple, almost time-to-collision criterion.

2.4 *Results and accuracy*

The high accuracy of the Laser Scanner hardware enables a highly accurate object tracking. Due to the 10Hz rotation speed of the scanner and the overlapped calculations, an object may have a 200ms latency (worst case) before being reported on the CAN bus. Its position accuracy is equivalent to the accuracy of the scanner, meaning an angle resolution of 0.25° and a range uncertainty of approx. 5cm. Tests with passing vehicles, driving at constant speed, indicate a velocity accuracy of within 1km/h to the correct velocity.

If the scanners are mounted on a vehicle, special care has to be taken to adjust the scanners properly. Since the 2d scanners see a plane section only, they have to be carefully adjusted horizontally to achive maximum range and the correct field of vision. If the vehicle rolls or pitches violently, the scanners may „see" the ground and report an obstacle in front of the vehicle. This is making it difficult for the vehicle guidance to decide wether to continue driving, and for safety reasons the vehicle normally has to slow down. The same difficulties occur when approaching a ramp. The scanner sees the ramp and reports it as an object, although the path is clear for the vehicle. However, most of these problems can be solved by the 3d-scanner. Since this scanner has more than one line on different elevation angles, it can estimate if the main line sees the ground or is on an obstacle. By empiric optimisation, almost all of those „ground objects" could be eliminated. In the current configuration, the 3d scanner supplements the arrangement of 2d-scanners and allows the vehicle guidance to decide wether an object is real or imaginary.

Safety The Laser Scanners have safety features to communicate any internal errors to the host computer. This allows the host computer to judge the reliability of the sent data. Upon startup, the sensor performs a self test and initialisation sequence to detect hardware failures. If an error has occured, a corresponding status message is sent to the host, otherwise normal operation is begun and „OK" messages are sent. When the sensor encounters an error, it tries to judge the severity of the error and sends a pre-defined error code in the status message. Depending on the error, the sensor may then continue operation, try to restart or go offline. In case of severe errors, two output switches are used to signal failures to an attached hardware which may then halt or park the vehicle and request service.

3 CONCLUSION

In the AF project, 4 Laser Scanners were used as an overlapping 360° surveillance system. The excellent accuracy and fine resolution make the scanners suitable for low-speed, high-res scanning (e.g. stop-and-go traffic), while the high range of up to 150m allows a sufficient look-ahead for high-speed driving. Since the scanners work with an active laser-light source, they are not limitied to daylight use. They can see through light rain, snow and fog, although this will reduce the range. The scanners have built-in signal processing to free the vehicle guidance system of the time-consuming obstacle detection and object tracking. The detected objects are then sent to the host in the desired fashion using a CAN bus. The signal processing can be configured by the host to suit the current driving situation (e.g. high or low speed). In the future, faster DSP's will allow more complex signal processing, thus further enhancing the quality of the object tracking algorithms. Together with an increase in accuracy this will result in an increased overall accuracy and reliablity.