Generalized Grid Framework for Multi Sensor Data Fusion

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Abstract—This paper presents a methodology for multi sensor data fusion that uses the accumulation grid idea for the representation of data. A Generalized Grid Framework is introduced to represent measurement data and fusion results in a common way. This allows the definition of standardized prediction and fusion operations and includes the variation between Cartesian and polar grids as well as the extension to 3D grids. It is shown that most of the typical object detection and tracking schemas can be represented by the framework. Two application examples including processing results from the field of automotive environment recognition are given to demonstrate special cases of the framework.

Keywords: Grid, occupancy grid, grid of evidence, fuzzy set, histogram filter, object detection.

I. INTRODUCTION

One of the key problems of the object detection task is the accumulation of sensor measurements over time. Typically sensors measure only certain features of a real object. Therefore it is mostly not possible to decide only on the basis of one single measurement whether an object is in the field of view or not. Only the step by step collection of the features over time allows this decision with a realistic degree of certainty. One way of representing accumulated measurements (respective features) is in a regular grid. In the grid the incomplete single measurements can be stored in a very intuitive way and can be completed over time. Figure 1 shows the general definition of a grid that is attached with two coordinate systems. The position of the grid is defined relative to a base coordinate systems with the help of the grid coordinate system that has its origin typically inside the grid extend. Additionally the grid has a frame coordinate system that lies on the frame edges of the grid. Both of these coordinate systems are able to express coordinates in a continuous way. The frame coordinate system is also the basis for the discrete access to the elements of the grid.

There has already been a lot of research in grid based approaches for sensor signal processing [1], [2], [3] compared different approaches for a grid map generation of an autonomous mobile robot. In [4] a modification of the evidence grids was shown which enables a 3D representation of the environment. Furthermore, several practical applications using grids were presented by the authors in the past. For instance, [5] proposes a multi target tracking using radar sensors. In this approach the grids were used to model a discrete fuzzy set. In [6] we presented a grid-based free space determination which was used for a parking assistance system. For this system a range camera was used. Finally, [7] showed a grid-based pre-crash system which utilised laser scanner measurements.

In section II of this paper we describe the generalization of our research results to a common theoretical platform. The subsequent section describes special theoretical cases of the grid framework’s configuration, which illustrate the flexibility of the system. The sections IV and V show practical applications of grid-based approach.

II. GENERALIZED GRID FRAMEWORK

The generalized grid framework has two main tasks: on the one hand it embeds the usage of the grid methodology into the Multi Level Fusion approach [8]; on the other hand it realizes the grid methodology as a prediction-correction algorithm. The grid methodology allows the low-level representation of most types of sensor data and is often assigned with the Early Fusion processing level. But this is not mandatory, as the grid and the grid elements have the only general task to store in a discrete time-space relation how strong a discrete element belongs to a certain entity. And this entity can be placed on low levels as well as on high levels of processing. It can represent the membership to the side geometry, to the ground area of an object or to the position of the object. In other words we
could say it can represent all: measurement data, features and objects.

The figure 2 visualizes two way of using grids in the Multi Level Fusion environment. On the left side several grids are representing different levels of processing and recognition. The right side combines the grid representation on a low level with a feature and object list representation on the two higher levels. The low level to high level processing is in both cases performed step by step beginning on the sensor level up to the object level of the entity car in that case. The Multi Level Fusion Methodology allows the usage of back loops to reach the refinement of higher level object hypotheses.

The usage of grids in a predictor-corrector-like schema requires the definition of common grid data types as well as generalized operations. The measurements are modelled as measurement grids to provide a common representation of data inside the framework. As the measurement grid is typically sensor specific, an alignment of the grid is necessary to allow the usage of a standardized update operation. The result of the update operation in the predictor-corrector-schema is the accumulation grid. The prediction due to the dynamic models of the components results in the prediction grid. The dynamic models include knowledge about the ego-motion of the sensor vehicle and the movement of objects inside the observation area.

The grid coordinate systems are defined for automotive applications mostly in relation to a moving vehicle coordinate system. The position vector $w_x$ indicates the position of the vehicle in the world coordinate system and is stored by the application. Every grid stores its relative position according to a base coordinate system. This base coordinate system is in the example of figure 6 the vehicle coordinate system. The accumulation grid A stores the relative position $v_x A$. Additionally every grid stores the position of its grid frame coordinate system. For the accumulation grid A this is the relative position $A f_x A g$. The measurement grid S stores in an equivalent manner the position $v_x S$ relative to the vehicle and the position of the grid frame $S f_x S g$ relative to the grid coordinate system.

A specific grid application is determined by special cases of the relations between vehicle, application grid and measurement grid. This includes that multiple measurement grids exist together with one accumulation grid. In opposite to that also a set of accumulation grids can be combined with one measurement grid.

III. Special Theoretical Cases

A. Global static grid

In the global static accumulation grid case the accumulation grid is aligned to the world coordinate system and is not changing the position. Nevertheless the relation between the moving vehicle coordinate system and the static accumulation coordinate system is changing. The grid coordinate system and the frame coordinate system of the accumulation grid are identical.

This arrangement of vehicle coordinate system and accumulation grid is typical for the map building case. Then sensor grid and vehicle coordinate system are moving simultaneously and the measurements gathered in the sensor grid are permanently mapped into the accumulation grid.
B. Moving windowed global accumulation grid

If the data shall not be collected all over the world coordinate system, the grid coordinate system of the accumulation grid can remain on the position of the world coordinate systems but the grid frame and the frame coordinate system are positioned locally near to the vehicle and moved together with the vehicle. In this case the grid is like a window surrounding permanently the vehicle position. This arrangement is used for instance for the accumulation of pmd-camera measurements for parking slot detection [6].

C. Object adaptive local accumulation grid

But the arrangement of the grids can also build up completely different from the both before. A very efficient way to model the occurrence of objects in the vehicle surrounding is to use object adaptive local accumulation grids for every objects. Then several accumulation grids are used to model all objects locally and a dynamic list of accumulation grids is used to manage new appearing and disappearing objects.

This version of the framework was used recently to fuse and accumulate the sensor measurements of three radar systems. Two short range radar systems and one long range radar system were used in [5] to detect vehicles on a highway and to estimate their rough vehicle shape.

IV. 3D GRIDS FOR A PRE-CRASH SYSTEM

New sensors like 3-dimensional measuring multilayer laser scanner systems will be introduced in the near future to deliver environment information for advanced driver assistant
systems. By fusing multiple sensors like laser and radar systems the reliability level of automotive safety applications will be improved significantly. The research of this section will concentrate on lidar data processing with a 3-dimensional occupancy grid and was embedded in the European Project PReVENT. PReVENT focuses in the sub-project ProFusion2 on data fusion issues for automotive safety applications. The pre-crash application example is taken from Apalaci [7] that is also a sub-project inside PReVENT.

A. System configuration

Pre-Crash systems are recently introduced vehicle safety applications which automatically monitor the vehicles surroundings and are able to detect collisions some hundreds of milliseconds before the crash itself [9]. This automobile safety system is designed to reduce the impact and the damage caused by a collision. To protect the passenger of the vehicle the safety system is able to

- provide brake and/or steering support,
- tighten the seat belts and adjust the head restraints,
- adjust the seat positions and close open windows and the sunroof,
- activate a warning in the instrument board.

Some systems are even able to slightly activate the brakes which will not avoid the accident but will reduce the injuries of the involved people and the damage to the car. The core of the pre-crash system should be able to provide following information:

- distance to the obstacle
- time to collision
- velocity information of the own vehicle and the obstacle (absolute or relative values and direction of the movement)
- estimation of the impact location
- decision whether a crash will occur or not

B. Grid based processing

For multi-layer laser data processing we used –among others– a 3-dimensional evidence grid structure. In this structure the space is tessellated in to several discrete 3-dimensional cells (see figure 10). By defining and changing the spatial dimensions of the grid cells itself, the level of details represented can be chosen adaptively. The grid representation was chosen as an effective way to handle huge amount of raw measurement data by collecting them in spatial "containers", which are the cells of the evidence grid. By doing this we were able to keep the cell information about the occupation state of a certain area in space. The approach is based on the grid processing method introduced by Alberto Elfes [1]. The basic structure has hereby been extended and modified to meet the requirement of the used sensors and the according application. The introduction of a 3-dimensional grid was motivated by the multi-layer type of the lidar. The laser scanner used 4 layers for sensing. This resulted in measurement information about the distance of objects as well as the height of a certain measurement point (see figure 11). By taking the third dimension into consideration and transferring them into the 3 dimensional grid the spatial configuration of an object could
be mapped into the grid structure up to a certain complexity. The representation of a 3-dimensional object in the grid can be seen in figure 12. In this example the theoretical outcome of the accumulation of lidar measurements in the spatial grid structure is illustrated. It can be clearly seen that the vehicle creates a distinct 3-dimensional cluster of occupied grid cells. This L-shaped segment can be used in subsequent processing steps to support e.g. a feature based classification procedure. In figure 13 lidar measurements of a parking lot are represented in the described grid structure. The coloured areas are the grid cells with an occupancy state higher than 0.5 what means that this area of space is with high probability occupied by an object. This is particularly true in this example since the occupied cells represent the outline of the cars parked there.

V. BLIND SPOT OBSERVATION WITH POLAR GRIDS

A further application example is the Blind Spot Observation using an optical distance measuring sensor. It utilises a local accumulation grid as described in section III-C, but non-adaptive here. Aim of the algorithm is a fast and robust detection and localization of objects in a determined area. Knowledge about free areas can be concluded from this occupancy information. For automotive applications a typical blind spot is besides the ego vehicle. Additionally, observing the areas left and right of a bus or a truck is a beneficially use too.

A. Optical distance measurement sensors

Examples for this kind of image sensors are the PMD (Photonic Mixer Device) camera or the UseRCams camera [10]. PMD cameras are available in resolutions from 64 x 16 up to 160 x 120. The UseRCams are this time developed in resolutions of up to 64 x 8. Both kinds of sensors use active infrared illumination. The PMD camera performs a phase shift determination algorithm to measure the distance. The UseRCams follows a different approach, since it measures the time-of-flight using a customized CMOS-sensor and the "multiple double short time integration" method (MDSI). As result both sensors deliver a three-dimensional image of the observed scene. For the aimed application, a possible place for the mounting could be at the side mirror looking back.
B. Local accumulation grid

The origin both of the polar sensor and the polar accumulation grid is straight below the side mirror under the sensor mounting (see figure 14). Their position is fixed with respect to the vehicle coordinate system. This means it is a Local (Polar) Accumulation Grid. Figure 15 illustrates the described configuration.

There are two main reasons for the decision to choose a local and not a global accumulation grid. If the ego vehicle is moving, we observe an also moving area, whose position is relative to the vehicle. Now, if there are moving objects inside the area, they change their position with respect to world coordinates in every case. Using the vehicle coordinate system as reference, they move in general but particularly not. An example for this case would be driving in separate lanes with the same velocity. As conclusion, when looking for moving object there is no difference between an ego-motion-compensated and a non-ego-motion-compensated grid. The second reason is that there can be an one-to-one mapping between the sensor grid and the accumulation grid.

C. Grid-based processing

The ground plane is separated into two height channels. If measurements are below a threshold $z_g$ they are assigned to the ground channel. Measurements above the threshold are assigned to the obstacle channel.

As a first step sensor data is mapped to the sensor grid. $R$ and $\phi$ are reconstructed for each pixel. Subsequent, the group of detections of each column of pixel in the image plane is put into the corresponding line of grid elements in $R$-direction (see figure 14 and 16). This correspondence is a big advantage of the polar grid approach. It simplifies the mapping of measurements to the grid. Additionally, the mapping of a probability distribution can be modeled easily and efficient. If the probability of a measurement is a function of $r$, all grid elements can be reached by iterating along a radial line of them.

At the next step, sensor grid is mapped into the accumulation grid. This operation is split in two parts. At first the accumulation grid is aged. This means that existing measurements become less important, since they were observed in the past.

The obstacle detection is performed evaluation the distribution of measurements along a radial row of grid elements. First of all, the sum of the occupancy values of the obstacle-channel is determined. An example frequency distribution is shown in 17. In a second run, the occupancy values are summarized again. At a certain threshold, the iteration is stopped at the corresponding grid element is marked as obstacle. After this step has been performed for all radial lines of grid element, the area where no obstacles are, is known. Furthermore, subsequent algorithms can cluster the obstacle detections and forward them to an object tracking. This tracking can then implement a object level predictor-corrector-stage.

VI. CONCLUSIONS

In this paper we are presenting a methodology for multi sensor data fusion that is based on the accumulation grid idea.
for the representation of data. For that purpose a new Generalized Grid Framework is introduced to represent measurement data and fusion results in one common way. It is shown that most of the typical object detection and tracking schemas can be represented by the framework. Two application results are given. The Application Apalaci demonstrates the extension of the Generalized Grid Framework to 3D grids. The blind spot observation shows that the Framework can also work with Polar grids. Future work will be concentrated on the further generalization of the fusion operations inside the grid and the general usage of confidence values in the prediction and fusion steps.

REFERENCES


