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Color Modeling by Spherical Influence Field in Sensing Driving Environment

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Abstract

The Advanced Driver Assistance System provides an attractive auxiliary equipment to improve the safety and efficiency of human driving, it has motivated an active research concerned with the sensing of driving environment. In this paper, technical issues of sensing driving environment are discussed, feasible scheme of sensor fusion is presented. In the module of image processing, an adaptive color model is proposed to detect color feature of the object around the car by creating color prototype as motivation. The color prototype is defined as an abstract representation of color feature in driving environment, it constitutes one spherical influence field in color space. Color prototypes are generated from experience learning, they are able to represent the comprehensive color feature of the object, and their spherical influence fields can exactly bound the region of colors in color space. To obtain the proper description of color feature, feature extraction is introduced to extract the representative color prototypes by dense weight estimation of color prototypes, so that unrealistic or biased color prototypes are removed from color model.

1 Introduction

With the massive influx of Information Technology in transportation industry, Intelligent Transportation has become an increasing important issue to improve the efficiency, reliability, and safety of modern transportation system. The Advanced Driver Assistance System (ADAS) is an essential section of ITS umbrella aiming to assist the driver in the execution of driving tasks, it attempts to help the driver in complex driving tasks, and may even take over the control of car driving as the driver wish. With such a motivation, automatic perception of driving environment has been a topic of research for recent years, great progress has been made by single sensor-based approach (radar or laser) and several commercial ADAS have been available. However, existing ADAS systems are limited in their application and reliability. Furthermore, single sensing information is not enough for ADAS to manage high lever driving tasks in dense traffic environment. To extend the application of ADAS in more complex traffic situation, there has been a growing interest in developing ADAS system used for urban areas where traffic signs, crossings, traffic jams and participants (motobikes, biycles or pedestrians) may be existed. This includes a class of techniques based on the information of multiple sensors ranging from road detection, object detection and classification to computer communication and interface, substantial research efforts are required to develop such a system by connecting the advances in sensing techniques with the basic study of sensor fusion [2]. In this paper, different driving scenarios are proposed, a driving environment model is discussed in both spatial and temporal dimension. The feasible scheme of sensing driving environment is presented by using the sensing information of vision, laser and radar sensors. In the module of image processing, an adaptive color model is built, which attempts to describe the color feature of objects by the creation of color prototypes in driving environment. The color distribution of object is firstly analyzed in different color spaces, L*a*b* color space is selected for color modeling because of its uniform and concentrated properties. The color prototype is defined as an abstract representation of object colors, it possesses one spherical influence field in color space. The combination of multiple color prototypes is able to fit the region of object colors by spherical influence fields of color prototypes. In the creation of color prototypes, unrealistic or biased color prototype may be generated because noisy colors exist in image sample, feature extraction is suggested to extract representative color prototypes by dense weight estimation. Through feature extraction, color model is composed of representation color prototypes, they have proper descrip-

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tion of object colors.

2 Driving Environment Modeling

Driving environment modeling is the fisrt important stage for sensing driving environment, all subsequent tasks are directly related on it (e.g. sensor fusion). The model of driving environment is built primarily based on the intention of application. In a simple application, a coarse model may be sufficient, such as collision avoidance around car. For a more complete ADAS system, exact environment model has to be provided that can reflect enough driving scenarios for the application.

2.1 Description of Driving Environment

The outdoor environment is dynamic and unstructured. Beyond the framework of driving environment, its characteristics are not easily outlined. In a typical driving environment, road is distinguished from the background in its geometry and visual features (smooth terrain with parallel side boundaries, different intensity and color with road sides), static or dynamic objects emerge and disappear randomly around the car, they are often pedestrian, bicycle, motorcycle, car, and truck. There are also traffic lights, lane and traffic markers to remind and guide the driver in driving environment. In the context of dynamic driving environment, it is necessary to consider it from the relation between road and existing objects both in spatial and temporal terms.

2.2 Spatial Modeling

In a driving environment, road and objects are observed by the driver from the view of projection. The description of driving environment, hence, also involved the characterization of their spatial properties. Visually, road consists of several lanes most often separated by color lines, which are essential geometry features to sectionalize the road area. In general, car, truck, motorcycle, bicycle and pedestrian are main objects in the road. These "traffic objects" constitute the spatial features of driving environment for their positions in road lanes. Given the observer of driving environment, considering the layout of traffic objects in front of car, it is possible to spatially classify the driving environment as follows:

- Obstacles in the same lane.
- Obstacles in other lanes with same driving direction.
- Obstacles in other lanes with opposite driving direction.

The traffic lights, signs and marks are necessary to be included into the model of when more complex environment modeling is required, and the objects above the road (traffic lights, signs and even bridge) are also required to be distinguish from the background for accurate modeling of driving environment.

2.3 Temporal Modeling

The driving environment is dynamic and varied, temporal characteristics of driving environment is also important to extract useful scenarios by excluding unintentional and stochastic motions. In terms of driving environment, it is equivalent to determining the feature of object motions in road area. Intuitively, there are static and moving objects existing in road area. Kinematically, these objects may longitudinally accelerate, decelerate, or move with near uniform speed, and laterally swing within the road area. In most cases, traffic objects may have different types of motions within one temporal phase. For example, "cut in" and "cut out" are typical traffic scenarios that include both longitudinal and lateral object motions.

3 Sensor Fusion

The characteristics of sensor reveal the fact that each sensor can only perceive part of environment features, which is not sufficient enough to comprehensively represent the driving environment. Furthermore, confidence level of sensor data still remains to be determined. The techniques of sensor fusion and integration are concerned with improving the sensing capacity of system by synergistic using redundant and complementary information of multiple sensors, they are able to obtain more accurate environment features that are impossible to perceive with individual sensor. Sensor fusion has great application potential in ADAS system. However, when developing the actual multi-sensor platform, a series of problems arise and need to be resolved, including not only the conventional issues of sensor fusion and integration but also some special cruxes in ADAS design. Figure 1 shows the scheme of sensor fusion for sensing driving environment, it includes three fusion levels. With the common geometry and time frames, sensor fusion is implemented with the following levels:

- Registration level: sensor data are registered to determine the correspondence among sensor data in both spatial and temporal dimensions.
- First fusion level: sensor data are fused to produce more accurate position-velocity information for detected objects, it uses the redundant position-velocity information of different sensors (radar, lidar, and vision)
- Second level fusion: complementary information are fused to infer new knowledge about the driving en-

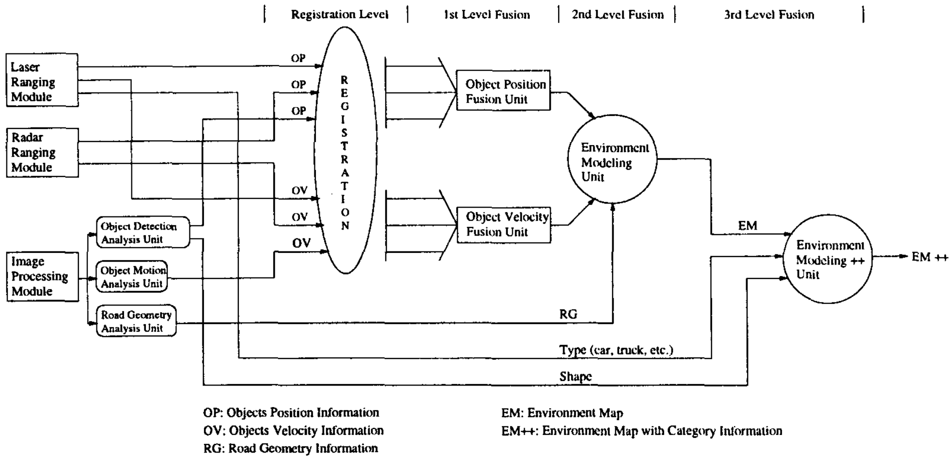

Figure 1: Sensor Fusion Fuctional Diagram

vironment. The position-velocity information of detected objects (from the first fusion level) and road geometry information (from vision) are fused to produce the primary perception map in which objects are characterized as being either stationary/moving or inside/outside the lane.

- Third level fusion: object type information (from lidar) and object shape (from vision) are fused to classified the objects as objects interest or not in the perception map.

4 Color Perception of Driving Environment

Color is an important perceptual information in sensing driving environment [4]. Without such information, some recognition tasks would become very difficult to perform, such as traffic lights, route guidance signs and color lane marking recognition etc. In the module of image processing, color image is acquired from dynamic outdoor environment including both artificial and nature objects (e.g. road, traffic marks, tree, sky etc.), its color distribution is complicated and varied with the following properties:

1. Color distribution of natural objects are not concentrated in color space, one object may include a wide range of colors.

2. The variation of outdoor light affects the color of artificial objects, color distribution of objects may change under different lighting conditions.

The color properties of traffic image require a color model to have the adaptation for environmental variation. In this case, an adaptive color model is essential to depict color feature of objects by self-adjustment. The common way of color modeling is to build appropriate color cubes for thresholding in color space, it suffers the difficult of proper threshold selection, because the distribution of colors has the irregular appearance in color space, simply thresholding is not sufficient to represent the complex of object colors, more exact color modeling is required for sensing driving environment.

4.1 Color Space Conversion

Color Modeling relies on not only segmentation algorithm but also the color space it uses. In color vision, all visible colors are specified in 3-D color space, each pixel is often defined by three values. There are many standard color spaces that have been defined and used to facilitate the analysis of color image [5]. RGB, L*a*b* and HSI are three most commonly used color spaces. The proposed color model is created by color prototypes with their spherical influence fields in color space. The following criterions must be considered to select the appropriate color space for color modeling:

1. Color space is required to have uniform characteristics in which equal distances correspond to equal perceived color differences.

2. Colors have more concentrated distribution in selected color space.

3. Color space conversion has simple computation.

Among different color spaces, RGB color space insures there is no distortion of initial color information, but color features are highly correlated, it is difficult to evaluate the difference of two colors from their distance in color space. HSI refers to perceptual color space, it closes to the way of human color perception. However, it has quite noisy color representation when lightness is low. L*a*b* color space possesses uniform property, it maps equally distinct color differences into equal Euclidean distances, and demonstrates more concentrated color distribution than others. The proposed color model is defined in L*a*b* color space, RGB-L*a*b* conversion is described as follows:

1. RGB-XYZ Conversion:

$$X = 0.431R + 0.342G + 0.178B \tag{1}$$

$$Y = 0.222R + 0.707G + 0.071B \tag{2}$$

$$Z = 0.020R + 0.130G + 0.939B \tag{3}$$

2. Cube-root transformation

$$L^* = \begin{cases} 116[Y/Y_n]^{\frac{1}{3}} - 16 & Y/Y_n > 0.008856 \\ 903.3[Y/Y_n] & Y/Y_n \leq 0.008856 \end{cases} \tag{4}$$

$$a^* = 500[f(X/X_n) - f(Y/Y_n)] \tag{5}$$

$$b^* = 200[f(Y/Y_n) - f(Z/Z_n)] \tag{6}$$

Where, X_n, Y_n, Z_n are XYZ tristimulus values of reference white point, $X_n = 95.05, Y_n = 100, Z_n = 108.88$, and

$$f(t) = \begin{cases} t^{\frac{1}{3}} & Y/Y_n > 0.008856 \\ 7.787t + 16/116 & Y/Y_n \leq 0.008856 \end{cases} \tag{7}$$

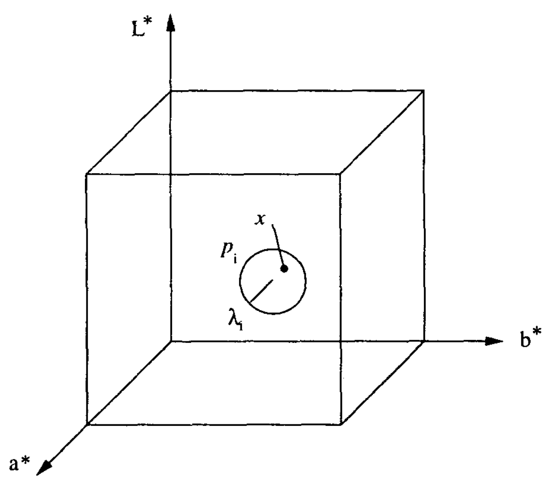

Figure 2: Spherical influence field of color prototype p_i

4.2 Color Modeling

The prototype mode is defined as the summary description of concept in cognitive psychology, it encodes the most central features of concept's instances. In the view of prototype mode, one color prototype is defined as a color set, it covers one color region which exactly represents part of object colors in color space. The color model of object is an comprehensive representation of object colors, it is constituted by many different color prototypes generated from sample learning.

4.2.1 Color Prototype

Suppose color sample C consists of $c_1, c_2, \ldots, c_n$ color elements. Each color element c_i is determined by its L*, a*, b* coordinate values, it represents one point in L*a*b* color space. Define color set p_i as one color prototype, it covers a spherical region with center c_i and radius λ_i in L*a*b* color space. The spherical region is defined as "spherical influence field" of color prototype p_i, its radius λ_i is the threshold of influence field (See Figure 2). The color x is regarded as color element of p_i if it is fallen into the influence field of p_i. Define d_i as Euclidean distance between x and c_i,

$$d_i = |\sum_{j=1}^{3}(c_{ij} - x_j)^2|^{\frac{1}{2}} \tag{8}$$

Then, x belongs to color element of p_i only if there is $d_i \leq \lambda_i$.

4.2.2 Region Fitting

The color prototype is able to represent part of object colors, its spherical influence field is isotropy. The combination of multiple color prototypes may fit the color region with irregular appearance. Define color model M consists of color prototypes $p_1, p_2, \ldots, p_m$, they are generated from color sample $C(c_1, c_2, \ldots, c_n)$ as follows:

1. First color prototype: The first color prototype p_1 is built based on the first color element c_1, its spherical influence field is generated with the threshold λ_{max} (See Figure 3). The pattern counter of color prototype k_1 is set to one. $k_1 = 1$. As long as subsequent color elements fall into spherical influence field of p_1, there are no additional color prototype to be created, pattern counter k_1 is incremented.

2. Additional color prototypes: Suppose one color element c_i of sample C falls outside spherical influence fields of any previous color prototypes, a new color prototype is created, which generates its spherical influence field with the center c_i and threshold λ_{max}in color space (See Figure 4). The pattern counter of color protype k_i is set to one, $k_i = 1$.

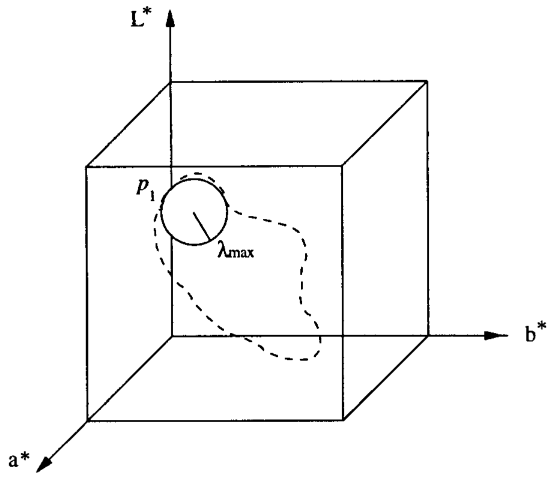

Figure 3: The creation of first color prototype

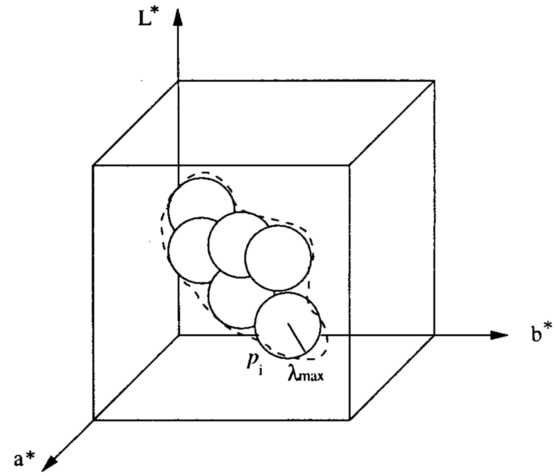

Figure 4: Region fitting by mutiple color prototype combination

4.2.3 Feature Extraction

The color sample is acquired from real color image, noisy colors may exist that bring unrealistic or biased color prototype creations, they have influence on proper color modeling. In this case, representative color prototypes are required to extract from the set of color prototypes, so that inappropriate color prototypes can be removed. Assume color model M includes $p_1, p_2, \ldots, p_m$ color prototypes, their pattern counters are $k_1, k_2, \ldots, k_m$. The pattern counter of color prototype indicates the number of color elements that fall into its spherical influence field, noisy color prototype has relatively low pattern number because of its sparse distribution in color space. The representative color prototypes are extracted by computing their dense weights as follows: Define w_i as dense weight of color prototype p_i, then

$$w_i = \frac{k_i}{\sum_{i=1}^{m} k_i} \tag{9}$$

Given the threshold of dense weight w_T, representative color prototype are extracted with the following condition:

$$\text{if } w_i \leq w_T \quad w_i \text{ is reserved}$$

$$\text{if } w_i > w_T \quad w_i \text{ is removed}$$

Then, color model is a set of color prototypes $M(p_1, p_2, \cdots, p_l)$ includeing all representative color prototypes derived from feature extraction.

5 Experimental Results

The proposed color model has been applied for road segmentation on the images acquired on-the-spot. Road color model represents the color features of road based on representative color prototypes. Through such a color model, road color image can be partitioned into road and no-road regions. Given road color model $M(p_1, p_2, \ldots, p_l)$, $I(x, y)$ is one pixel with l, a, b color values in road color image, its thress color values represents one point I^* in L*a*b* color space. Then, color pixel I belongs to road region only if point I^* falls into the spherical influence field of one representative color prototype. Define $h_1, h_2, \ldots, h_l$ as Euclidean distance between I^* and representative color prototypes $p_1, p_2, \ldots, p_l$, then color I^* is classified into road color as long as there is one distance h_i satisfies,

$$h_i \leq \lambda_{max}$$

In road color image, road region is segmented by carrying on above color classification pixel by pixel. Figure 5 shows one road image sequence with image size 256×256. The sample of road colors is selected from a trapezoid shaped area in sample road image, road color model is built based on it. In our experiment, λ_{max} and w_t are set as: $\lambda_{max} = 5, w_t = 10$, there are 1648 representative color prototypes generated from the given sample. The result of road segmentation are show in Figure 6.

6 Conclusion

The proper perception of driving environment is essential for driving assistance in ADAS system. In this paper, spatial and temporal characteristics of driving environment are discussed, feasible scheme of sensor fusion was proposed. In the module of image processing, an adaptive road color model was studied, it is built by representative road color prototypes with their influence fields in L*a*b* color space. To demonstrate its ability of color clustering, color-based road segmentation has been tested by using such a

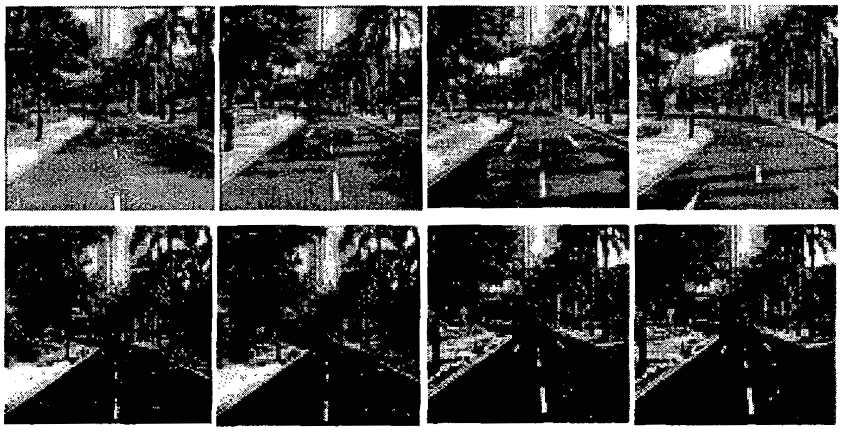

Figure 5: Road segmentation results

color model. The realization of road segmentation proves that road color features can be properly described by color prototype creations and representative color prototype extraction.

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