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AGV Guidance System: An Application of Simple Active Contour for Visual Tracking

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Abstract**—** In this paper, a simple active contour based visual tracking algorithm is presented for outdoor AGV application which is currently under development at the USM robotic research group (URRG) lab. The presented algorithm is computationally low cost and able to track road boundaries in an image sequence and can easily be implemented on available low cost hardware. The proposed algorithm used an active shape modeling using the B-spline deformable template and recursive curve fitting method to track the current orientation of the road.

Keywords**—**Active contour, B-spline, recursive curve fitting.

I. Introduction

AUTONOMOUS guided vehicles have been attracting tremendous attention among researchers and have found many application including commercial, military, healthcare, automated warehouses and other hazardous related areas. To perform these tasks more effectively and to navigate in an unstructured environment vision becomes invaluable. Vision can give a lot of information that can be examined by AGV's on board vision processing system that provide effective control for path findings and navigational control. The images captured by the visual system are interpreted to extract meaningful information such as position, road marking, road boundaries and direction of vehicle's heading.

Many different vision based road tracking system have been developed worldwide, each of them utilized different characteristics such as different road models (2D or 3D, straight or curve), acquisition devices (colour or monochrome camera), and computational methods (template matching, Hough, neural network, mono or stereo vision). Conventionally these systems are either based on feature based technique or they used a road model for road boundaries detection [1]. In the feature based approach tracking is performed by combining the low level feature such as painted lines[2]–[5] or edges[6]–[7] of road boundaries. However these techniques suffer from noise or occlusion.

In contrast with feature based technique, model based approach is based on prior model like straight line [8], [9] or parabolic [10], [11] or spline curve [1] of the tracking road. It requires few parameters to represents road boundaries. In this way a model, based on robustness against noise and missing data is compared to feature based technique.

In this work a primary result of a simple active contour based visual guidance systems for outdoor AGV application is presented. The objective of this research is to develop a simple approach for road-tracking system which can be used integrate with the existing and low cost hardware. A B-spline function is used to define the initial contour of the image, and then the image processing is performed on this image to extract feature points. Subsequently, active shape model concept is used for contour deformation integrated with recursive curve fitting method for pose and orientation measurement. The following section introduces the B-spline function for road model while section III presents the image processing method. Section IV discusses the active shape modeling and recursive curve fitting technique. Finally section VI will end the paper with the primary result and future work.

II. Road Model

As mentioned earlier, the model based approach is the most appropriate approach for road tracking application. In our project a second order B-spline curve with 3 control points {Q-1, Q0, Q1} is used as shown in equation 1 for represent the road boundary, which provide C^{-1} continuity. Although some of the tracking systems [1] use cubic B-spline function to model the road boundary. To keep computational cost low and for faster processing 2^{nd} order B-spline is sufficient for our application.

$$c(s) = \sum B_i(s)*Q_i \quad i = -1 \text{ to } 1 \tag{1}$$

where B(s) are the spline basis function and Q are the control points or control vector. As shown in figure 1 a set of control points is use to describe the mid line of the road by using B-spline function. An offset D is added to the function to keep tracking the mid line of the road which is the distance form the right side or the left side of the road. The mid line of road model can be expressed by a B-spline function as:

$$L_{mid} = [1 \ s \ s^2]*M_0*[Q_{0-1}, Q_0, Q_1]^T + D \tag{2}$$

$$M0 = \begin{bmatrix} 1 & 0 & 0 \\ -2 & 2 & 0 \\ 1 & -2 & 1 \end{bmatrix}$$

where M0 is the span 0 matrix.

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Fig. 1 B-spline curve on image

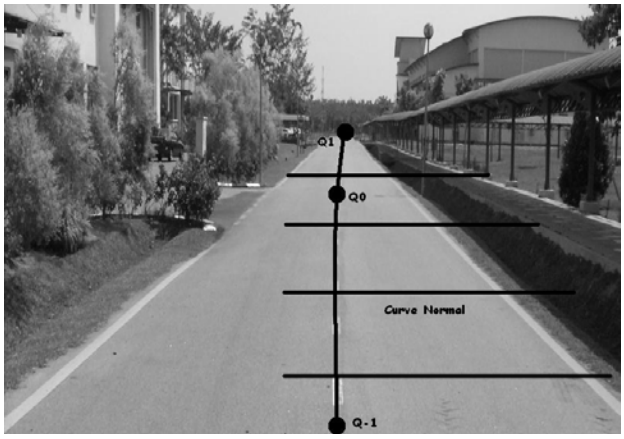


Fig. 2 Normal vector along the curve

III. Feature Extraction

Until now there are many of methods proposed for image processing and feature extraction. However, most of them are very complex or excessively computationally costly. When working on a visual contour, at any given instant, an estimation is available of the position of a tracked image-contour and this can be used to define a "search region" in which the corresponding image feature is likely to lie. Image processing can then effectively be restricted to this search region. The search region is formed by sweeping the normal vector of a chosen length along the entire spline curve as shown in figure 2. Edge detection along the normal is accomplished by simple one-dimensional convolution and subsequent thresholding. The convolution kernel used, as proposed in [12] can be seen in equation 3.

$$K = [-0.375 \quad -0.625 \quad 0 \quad 0.625 \quad 0.375] \tag{3}$$

Pixels on the normals are classified as feature or non feature by thresholding the absolute value of the output of the convolution.

In order to perform the one-dimensional convolution, the image intensity has to be sampled at regular intervals along the normal. Doing this on an arbitrarily oriented normal will generally produce undesirable artifacts and possible multiple samples form the same pixels because of the discrete nature of the digital image as shown in figure 3.

To cope up with this problem and to keep the processing requirement as low as possible, normal extraction is performed with a Bresenham line algorithm which is one of the oldest algorithm in computer graphics.

IV. Road Tracking Algorithm

The design road-tracking algorithm is based on a combination of active shape modeling defined by using the B-spline function and recursive curve fitting methods for tracking the current orientation of the road over time. First we will look at active shape modelling in detail then, we will discuss a curve fitting method.

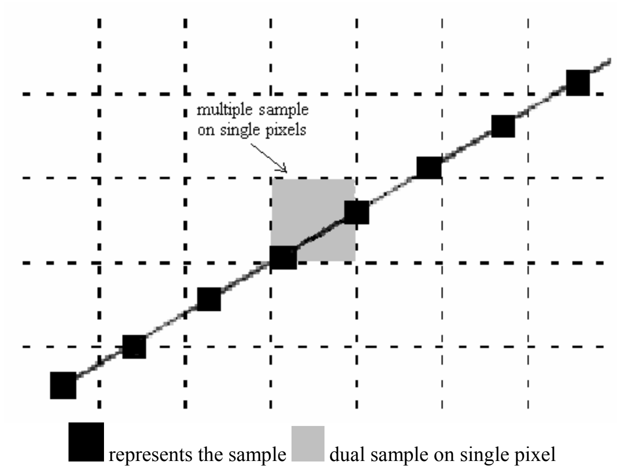


Fig. 3 Multiple samples on single intensities of pixels

To begin with we need to be able to represent shape deformation of a road boundary, which is a non rigid contour (B-spline contour). This is done using the concept of a shape-space [13]. A shape space is a linear mapping of a "shape-space vector" X to a spline vector Q as shown in equation 4.

$$Q = WX + Q_o \tag{4}$$

where W is N_Q by N_x shape matrix, X is a shape vector $X \in S$, S is the set of all possible configuration of state. X also called state vector because it represent the current state of the object and Q0 is a template curve.

Two types of shape space are commonly used in visual tracking applications. First is the space of Euclidean similarities which give 4 degrees of freedom and suitable for planner object tracking. 3D rotation and perspective effects cannot be accommodated by Euclidean similarities. The second space in common use for object tracking is the Affine space, which have 6 degrees of freedom, computationally simple and able to handle translation, rotation, and perspective effects. Therefore, affine spaces are a suitable choice for the road tracking application. Affine space can be viewed as the class of all linear transformation that can be applied to a template curve $c_0(s)$ as shown in equation 5.

$$c(s) = d + A^{*}c_o(s) \tag{5}$$

where d is a two dimensional translation vector and A is a 2*2 matrix which corresponds to remaining four affine motion. The affine space can be represent in a shape space with template Q_0 and shape matrix W as shown in equation 6.

$$c(s) = WX + Q_0 \tag{6}$$

$$W = \begin{pmatrix} 1 & 0 & Q_0^x & 0 & 0 & Q_0^y \\ 0 & 1 & 0 & Q_0^y & Q_0^x & 0 \end{pmatrix},$$

$$X = (d1, d2, A11\text{-}1, A22\text{-}1, A21, A12)^T$$

The first two column of the shape matrix W represents 2D translation and remaining four columns corresponds to four affine motions and X is the state vector.

Now the second part of the visual tracking algorithm is to use curve-fitting technique to measure the current position and orientation of the road boundaries.

The image features were expressed in the form of a spline curve c_f which is obtained by one dimensional image processing along the normal.

If $c_f(s)$ is the feature curve and c(s) is the possible fitted curve then the fitting problem is shown in equation 7.

$$r = \arg\min \|c(s) - c_f(s)\|^2 \tag{7}$$

which is the square of the residual norm. Generally, searching measurements made from images are noisy. This is due to several reasons. In the presence of noise, finding the minimum of r is really a difficult task, and it is necessary to include additional information. To prevent the measurement from noise Tikhonov regularization is used, which is perhaps the most common, and well known of regularization schemes. It biases the fitted curve towards the mean shape $c_m(s)$ to the degree determined by a regularization constant Ω as shown in the equation 8.

$$r = \arg\min \{\Omega^2 \|c(s) - c_m(s)\|^2 + \|c(s) - c_f(s)\|^2\} \tag{8}$$

where c_m is the mean shape and Ω is the regularization parameter. If the regularization parameter is very large, the term $\|c(s) - c_f(s)\|^2$ is negligible to that of $\Omega^2\|c(s) - c_m(s)\|^2$ of the equation 8 and we find that $\lim_{\Omega \to 0} r = c_m$. With a large amount of regularization, we effectively ignore the data (and any noise on the data) completely and try to minimize the solution semi norm which is possible by choosing the default solution. On the other hand, if Ω is small, the weighting placed on the solution semi-norm is small and the value of the misfit at the solution become more important. Of course, if Ω is reduced to zero, the problem reduces to the least-squares case shown in equation 7 with it extreme sensitivity to noise on the data. Equation 9 shows the fitting equation in term of shape state vector X.

$$\min X = \Omega^2 \|X - X_m\|^2 + \|c(s) - c_f(s)\|^2 \tag{9}$$

To avoid the influence of position and orientation of the tracking contour in the regularization term, weight matrix L^s is introduce as shown in the equation 10.

$$\min X = \|X - X_m\|^T L^s \|X - X_m\| + \|c - c_f\|^2 \tag{10}$$

where $L^s = \Omega H$ and H is the space of B-spline function.

To solve this equation a normal displacement method is used which is a standard technique in computer vision. The normal displacement method measures the displacement between two corresponding points of the curves. If n(s) is the normal vector to the curve c(s) so that the distance between corresponding points is given by equation 11.

$$\|c - c_f\|^2 \approx 1/N \sum_{i=1 \text{ to } n} [(c_f(s) - c(s)).n(s)]^2 \tag{11}$$

The final solution of the normal displacement between two curves is given by equation 12.

$$\|c - c_f\|^2 \approx 1/N \sum_{i=1 \text{ to } n} [((c_f(s) - c(s)).n(s) - h(si)^T[X - Xm])^2 / e^2 \tag{12}$$

where

$h(s) = n(s_i)^T U(s_i) W$

e_i^2 = measurements error = N

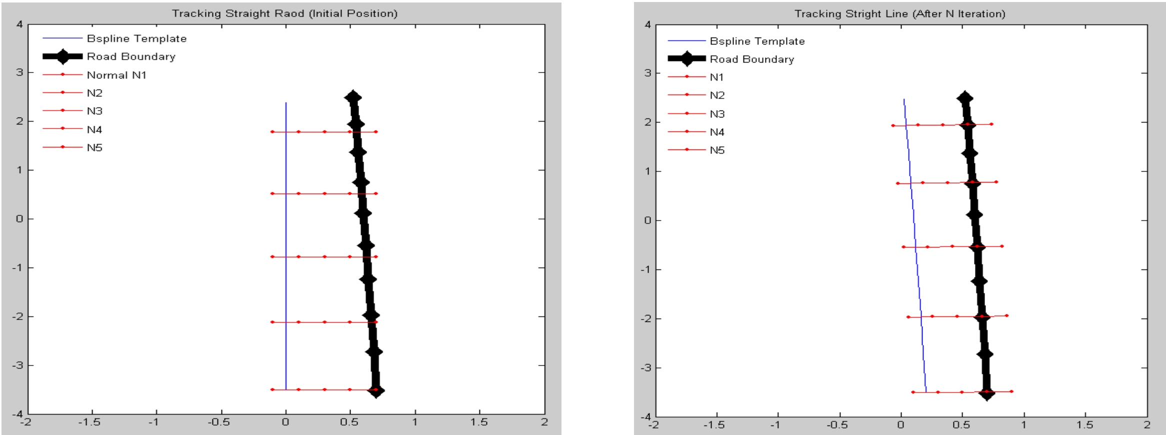
The detail of the normal curve fitting technique can be found in [13]. The pose and orientation of the tracking road boundary can be measure directly from the shape vector X.

V. Result and Discussion:

In this paper a real time B-spline based road tracking system is presented working on flat road and painted boundaries. The initial results on MatLab show that the system effectively tracks a range of road models, such as straight road model as shown in figure 4, and parabolic models as shown in figure 5. This active contour deforms into the shape of the road boundary in a few iterations. Based of this deformation, we can easily calculate the pose and orientation of the road boundary. The accuracy of the simulation will certainly depend on the number of samples used in the calculation. This will need to be considered vis-à-vis the processing time, i.e. the response time that can be tolerated by the vehicle guidance system. In this initial work, assumptions that the road boundaries are well painted, and one feature is found on each normal, are utilized. This undeniably will influence the robustness of the guidance system.

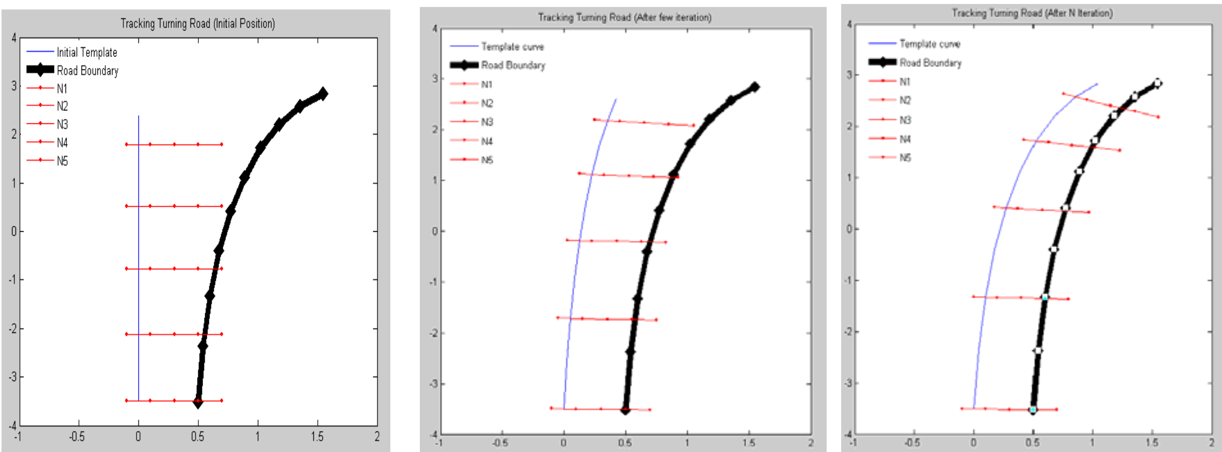
VI. Conclusion and Future work

We have successfully developed a simple visual-based vehicle navigation system, which can easily be modified to suit actual navigation requirement. For the case of multiple feature or critical shadow conditions, favourite feature measurement for example using the strongest feature response



(a) (b)

Fig. 4 Shows the simulation result of the tracking algorithm for straight road boundaries a) Initial condition of the of the B-spline template. b) Final position after N iteration.



(a) (b) (c)

Fig. 5. Tracking of the curve road a) Initial Position of the contour b) After few iteration c) After N iteration

or interior-exterior likelihood method should be use. In order to improve tracking and to make algorithm more robust in case of unpainted road lines, probabilistic framework will be explored.

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