Determining Angles with a Movable Observer

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Abstract

We present a view planning approach to determining angles between two-line junctions on an object. Using view planning we demonstrate an ability to determine such angles without reconstruction of 3D properties, and without using known camera displacement. The core in our approach is a two-step view planning strategy based on two simple motion patterns. The view planning is controlled using local extrema in the apparent (viewed) angle. We demonstrate the approach on real images and experiments show an accuracy in determined angle which is better than ± 1 degrees.

1 Introduction

This paper addresses a narrow, yet important problem in computer vision: determination of the angle between edges on objects. From a single image the problem is ill-posed,- the inherent loss of a dimension in the projection onto an image plane makes it impossible to compute the true angle in 3D space between two lines on an object. In an attempt to circumvent stability problems associated with 3D reconstruction techniques, we approach the problem using a movable observer. We investigate a view planning strategy enabling the control of a monocular, movable camera-head. The aim of the motion strategy is to move the camera to a view point, from which the angle in the image is identically equal to the true 3D angle. Figure 1 illustrates the problem.

The true angle between edges on an object is a 3D property. Thus, most work addressing this problem uses 3D reconstruction techniques in order to create an internal model of the viewed scenario. From this model different properties can be computed, among those, orientations of lines, i.e., relative angles. While we will not consider the direct approach to 3D reconstruction using laser range finders, most reconstruction techniques involve measurement of disparity or flow. The amount of work is large and beyond the scope of this paper.

Interesting work in direct relation to the problem addressed in the present paper can be found in [2] and [1]. Both approach the problem of mapping a measured, apparent angle to a hypothesis concerning the true angle using different aspects of the joint probability distribution between true and viewed angles. The probability distribution is used to rank matchings of line assemblies in single image interpretation. Thus, hypotheses are qualified, but not certain.

Increasing thought is being given to utilizing a movable observer to re-locate a regular camera to a position from where the addressed problem has an especially simple formulation in terms of interpreting the image information. The basic ideas in [6] are somewhat similar to those of the present paper. Their approach is to identify and track an image line over an image sequence and move the camera so as to maximize the length of the line. Then another line is selected and the length of this is maximized, though constrained by keeping the first line at its maximum length. The resulting view will be one of several generic ones for the particular object. These generic view can be predicted from the model of the object, and the recognition process is reduced to a 2D pattern recognition problem.

The active approach to true angle determination presented in this paper is also based moving the camera to a generic view point, but is based exclusively on local extrema in changes in image line directions;- a very stable image feature. Moreover, our approach is indifferent to calibrated camera motion, i.e., does not require positional feedback from the robotic system

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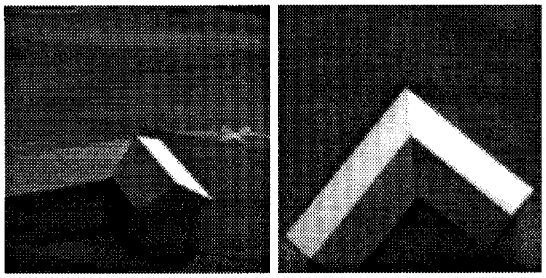

Figure 1: Left: what is the true angle between the two edges identifying the roof edge of the house? The problem is ill-posed using only a single view. Right: in this image the apparent (image) angle is identical to the true angle, since the plane spanned by the two edges is fronto-parallel to the image plane. This paper proposes a camera motion strategy to move to such a position from an arbitrary starting point.

used to move the camera.

The work presented in this paper is limited to single object, polyhedral scenes, but the approach is extendible to any 2D aggregate local geometric entity. When camera motion is involved, occlusion becomes a problem. This we have not yet addressed. We have assumed that a pair of image line segments can be selected, which represents a coplanar pair of 3D lines segments in the scene. Moreover, we assume it is possible to perform fixation on the intersection of these lines, using a single camera with 6 spatial degrees of freedom. The latter can be accomplished by mounting the camera on a manipulator.

The present paper will not go into details of the mathematical analyses of the problem/approach. These analyses may be found in [5]. This paper presents a simple camera motion strategy for moving to the generic view point and for the first time reports results from experiments on real images using this approach.

The outline of the paper is as follows: section 2 briefly presents the visual potential of a fixated two-line junction as viewed from a free to move camera. Section 3 presents two suitable, reactive motion patterns based on the image of the junction. In section 4, we introduce a simple two-step control strategy capable of moving the camera to the desired position. The flow of the control strategy is determined by detection of extrema in the change in apparent angle as the camera is moved. We then report on experiments performed on real images in section 5 and finally summarize on important aspects of the proposed approach.

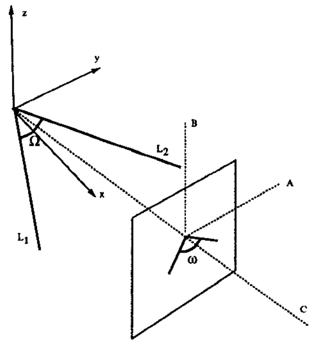

Figure 2: The Fixated Coordinate System (xyz) is defined relative to the junction formed by L_1 and L_2. A camera coordinate frame, $\vec{A}$, $\vec{B}$ and $\vec{C}$ determines the projection of the junction and the apparent angle, ω.

2 Characteristic view variation

The relationship between apparent (viewed) angle and true angle as a function of view position has been investigated by several researchers, [2, 1, 3]. The aim has been different and the exact formulations differ, but a fairly simple geometric analysis will reveal the following relation:

$$\begin{aligned} \tan(\omega) &= \mathcal{F}(\Omega, \theta, \phi) \\ &= \frac{2\cos(\theta)\sin(\Omega)}{(\cos^2(\theta)+1)\cos(\Omega) - \sin^2(\theta)\cos(2\phi)} \end{aligned} \quad (1)$$

In eq. (1) the variables are the following: Ω is the true 3D angle between two lines; ω is the apparent angle when fixating the junction point in the image center; θ and ϕ specify the position of the camera in spherical coordinates relative to a coordinate system centered at the junction point, having x-axis along the bisecting line and z-axis along the normal to the plane spanned by the two lines of the junction, (see figure 2). This coordinate system is object centered and will be referred to as the Fixated Coordinate System, (FCS).

Noteworthy about the presented expression for the apparent angle is that it shows ω as a function $\mathcal{F}(\Omega, \theta, \phi)$. I.e., the apparent angle only depends on the true angle and the view point on the unit view sphere specified by θ and ϕ. Parameters such as focal length and distance to junction do not influence ω. Figure 3 shows a plot of $\mathcal{F}$ functions over the entire northern hemisphere of the view sphere for some true angle. It is seen that the topology is that of a saddle surface; this is the case for all true angle values. In the saddle point, the apparent angle is identically equal to

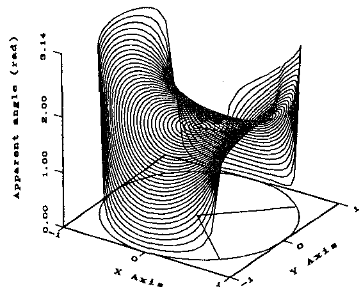

Figure 3: A plot of apparent angle over the northern view semi-sphere. The true angle in this case is 90°. Each point on the surface represents a three-tuple $< x, y, \omega >$, where x and y specify a view point in the FCS according to the sphere equation, and ω is the apparent angle.

the true angle,- an observation which is paramount to our approach.

The two principle axes of the saddle-surface $\mathcal{F}$ functions are coincident with the x and y axes of the FCS. This is what we can exploit when we define visual events from zero-crossings in change of apparent angle during motion. Prediction of these events requires that we can obtain reactive camera motion patterns which can be generally modeled by characteristic trajectories. We have developed two such motion patterns; these are presented in the subsequent section.

3 Available motion patterns

To be able to analyze the effect of moving the camera in relation to the scene, we need a qualitative model of the trajectory resulting from following some motion scheme. It has been observed recently, [4], that fixation in combination with translation results in camera trajectories that are circles in space. I.e., if translation is performed parallel to the image plane, followed by re-fixation at a static point of interest in the scene, then repetition will lead to a piecewise linear approximation to a circle.

For the purposes of this study two special cases of the above described pattern has been investigated. Each case is specified by the direction in which the translation is performed. The two analyzed directions have been the direction of the bisecting line, and the perpendicular direction. Figure 4 illustrates this concept.

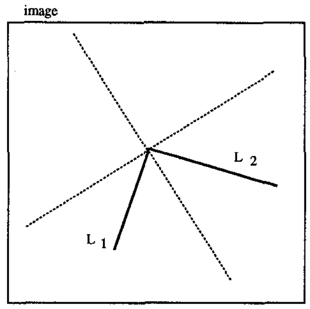

Figure 4: Regardless of the value of true and apparent angle for a junction, two phenomenon-specific image directions are available: the direction of the bisecting line and the perpendicular direction, (dotted lines).

We have developed a mathematical model for the trajectories resulting from engaging such a motion pattern. The analyses have been done to establish how the trajectories depend on the staring point on the view sphere, i.e., the position of the camera valid when the motion is initiated. The mathematical detail of deriving such a model will be omitted, but can be found in [5]. The important factor is that regardless of initial view point relative to the junction, the trajectories are qualitatively similar. Figure 5 show examples of trajectories when using the bisecting line as direction in which to translate. Note that, when viewed from the top of the viewed sphere, (right-most plot in the figure), they are all fairly 'parallel' to the x-axis of the junction centered coordinate system, the FCS. When using the direction perpendicular to the bisecting line for translation, the same type of curves are obtained, only 'parallel' to the y-axis.

The two motion patterns will subsequently be referred to as **Motion Along Bisector** and **Motion Across Bisector** respectively.

4 A simple control strategy

As demonstrated in the previous section we have at our disposal two motion patterns. When comparing to the plots of the view varying apparent angle, (figure 3), it is seen, that **Motion Along Bisector** will at some point cross the y-axis of the FCS, resulting in a local minimum in apparent angle. Conversely, **Motion Across Bisector** will lead to crossing the x-axis, where a local maximum will be experienced.

Our control strategy evolves from this basic observation. The most simple way to exploit this is to make camera motion control a two-step process, (figure 6.

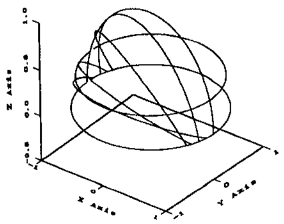

Figure 5: A set of representative trajectories resulting from the **Motion Along Bisector** pattern. In each case the elevation of the view point at which the motion is engaged is $\theta_0 = 70$ degrees, shown as the smaller circle over the unit circle in the bottom of the plot. There is a curve for $\phi_0 = 0, -20, -40, -60, -80$ degrees.

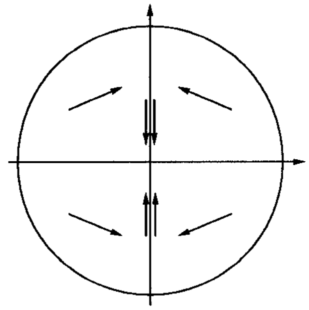

Figure 6: Schematic top view, (north pole of junction centered view sphere), of the proposed two-step view planning strategy. The characteristic local minimum/maximum of a saddle surface is utilized to provide indicators for when to halt the two motion patterns. Motion is terminated at the saddle point, from which it is known, that the apparent angle equals the true angle of the junction.

By first engaging in **Motion Along Bisector** and watching for a local minimum in apparent angle, we can position the camera somewhere close to the y-z-plane. If this is followed by **Motion Across Bisector**, the saddle point is reached upon detection of a local maximum in apparent angle.

In figure 6 it is indicated that depending on what octant the motion is engaged, there is a difference in the direction of the arrows, i.e., to get to the y-z-plane using **Motion Along Bisector**, it is necessary to move in that direction. This can only be ensured by inspecting the sign of the change in apparent angle as the camera is moved. Initially, one may chose to move along the bisecting line in the the general 'direction' of the junction lines. If after a short while the apparent angle is determined to be increasing, the translation needs to be reversed, so as to get decreasing apparent angle. That way it is known that the camera is approaching the y-z-plane. Same arguments are valid for the second step, **Motion Across Bisector**, only here the apparent angle must *increase*.

In pseudo-code, the complete strategy can be expressed as below, (where, e.g., $\omega(N)$ indicates the apparent angle in frame N):

```
process Basic_Control_Strategy()
    fixate on chosen junction;
    compute ω(1);
    set Motion Along Bisector;
    set positive speed;
    repeat
      translate camera using chosen pattern/speed
      fixate on junction;
      compute ω(N);
      compute Δω(N);
      if Δω(N) > 0
         set negative speed;
    until Δω(N) = 0 (Local minimum in apparent angle)

    set motion across bisector;
      set positive speed;
    repeat
      translate camera using chosen pattern/speed
      fixate on junction;
      compute ω(N);
      compute Δω(N);
      if Δω(N) < 0
         set negative speed;
    until Δω(N) = 0 (Local maximum in apparent angle)

    assign ω(N) to the junction as true angle;
end Basic_Control_Strategy()
```

5 Experimental Results

We have implemented the proposed strategy on a system capable of moving a camera around a test object. Figure 7 presents 6 frames picked from a sequence of 104 acquired using the presented view planning strategy to guide the camera from a randomly chosen view point towards the canonical view point. It is possible to get a feeling for how the camera moves relative to the object. In this example the strategy terminates at an apparent angle of 90.19°. The true angle measured on the object is 90.0°.

We have performed on the order of 100 experiments

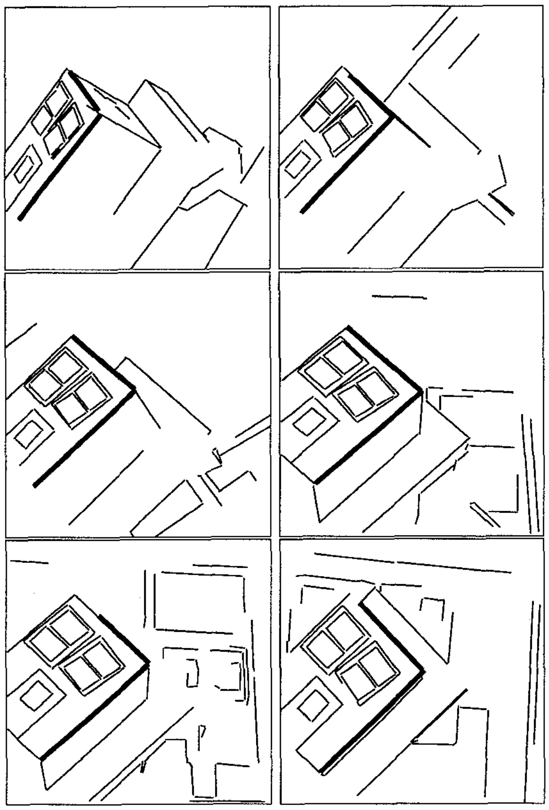

Figure 7: 6 frames picked out with equal spacing from a sequence of 104 acquired in the process of executing the basic view planning strategy on a test object. The switch from **motion along bisector** to **motion across bisector** takes place between number 4 and number 5 of the displayed frames.

of this kind using test objects with true angles of 45°, 90° and 135°. In each experiment the camera is initially positioned at random on the view sphere around the object and control is given over to the automatic strategy. Each experiment involves acquisition of 50 to 150 images depending on the initial view point. In all these experiments the estimated true angle has been within ±1° of the measured true angle.

6 Summary

We have addressed the problem of determining true angles in scenes containing static objects. The paper presented a simple two-step view planning strategy based on using easy to implement motion patterns. These patterns result directly from performing repeated operations of translation followed by refixation. The purpose of the view planning is to move the camera to a position from where the true angle can be computed directly from the image. Thus the approach completely circumvents reconstruction of metric 3D properties.

The strategy is controlled by event type features of the changing appearance of the junction under investigation. These events are extrema in the apparent angle during motion of the camera. Using these events, it is possible to avoid the use of absolute motion, i.e., positional feedback is not required. Moreover, knowledge about focal length is not required, like it is not necessary to estimate the distance to the object.

An extensive set of experiments on real images using a robotic setup controlled by the proposed strategy, have demonstrated an accuracy in true angle determination within ± 1 degrees.

The most important feature of the proposed approach is the use of local extrema in apparent angle to control the camera motion. Experiments showed these to be very stable in real images.

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