Reactive View Planning for Quantification of Local Geometry

Claus Brøndgaard Madsen* and Henrik Iskov Christensen†
Laboratory of Image Analysis
Institute of Electronic Systems
Aalborg University
DK-9000 Aalborg Ø, Denmark

Abstract

We present a view point planning strategy for determining the true angle between legs of junctions in a polyhedral scene. The strategy results in a reactive visual behaviour guiding the camera towards a canonical view point producing a fronto-parallel projection of object faces. From these views the angle in the image is identical to the true angle, thus the method does not involve reconstruction.

Qualitative visual events, e.g., zero-crossings in the rate-of-change of measured, apparent angle, are used to control the motion of the camera, resulting in independence of positional feedback.

1 Introduction

Due to the inherent loss of a dimension in projecting a scene onto an image plane, interpretation of object properties from a single image is mostly ambiguous. This poses a serious problem for recognition based on stored object centered (CAD) models.

We have focused on analysis of the relationship between the true angle between lines in the scene and the corresponding apparent angle between projected image lines. We present a reactive view planning approach to measuring the true angle by moving the camera to a view point producing a fronto-parallel projection of the junction under examination. The merit of the presented approach is that it does not involve reconstruction of 3D properties and does not rely on feedback of camera position.

The problem of relating viewed angles to true angles in single image interpretation has been addressed in a variety of approaches, though it is an ill-posed problem with no exact single image solution. Some have investigated applications of an estimated joint distribution function linking apparent and true angles to quantify the probability of an interpretation, [2, 1].

Geometric hashing incorporates the different perspective appearances into a pre-compiled data structure, [5]. Other work uses tables of transition probabilities that, among other things, account for perspective distortion, [4]. These methods will only work when several related two-line assemblies are analyzed in parallel and used to over-constrain the solution.

The basic ideas in [7] are similar to those of the present paper. Their approach was 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 was selected and the length of this was maximized, though constrained by keeping the first line at its maximum length. The resulting view would be one of several generic ones for the particular object. These generic views could 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 on moving the camera to a generic view point, but is based exclusively on changes in image line direction, which generally is a very stable feature.

Section 2 presents definitions of basic terms and shows that there is a generic characteristic relation between view point and apparent angle. Our approach is based on a possibility to infer camera position relative to the object by watching the change in apparent angle during camera motion. Section 3 introduces two simple camera motion patterns, followed by a brief overview of obtainable positional knowledge in section 4. These two sections provide a brief overview of previous work. Refer to [6] for greater detail. A

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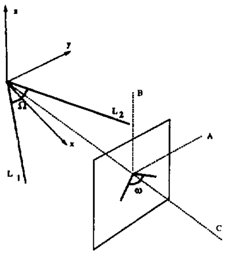

Figure 1: The Fixated Coordinate System (xyz) is defined relative to the junction formed by L_1 and L_2. A camera coordinate frame, $\vec{A}$, $\vec{B}$ and $\vec{C}$ determines the projection of the junction and the apparent angle, ω.

view planning strategy is defined in section 5 and an application to real images is presented. Section 7 summarizes and outlines future research directions.

2 Visual Potential

A paramount to our approach is the relation of all observations to an object centered coordinate system. Thus, all characteristics of observations hold within them qualitative information about the current position of the camera in this coordinate system. To this end we shall define a local coordinate frame for the junction under observation. Fixation on the origin of the local frame is assumed for all view points.

Definition: *Junction:* A junction is formed by two lines in 3-D space, L_1 and L_2, intersecting at a point Q_F. These two lines span a plane.

Definition: *True angle, Ω:* The interior angle between the two space lines of a junction is called the true angle. $\Omega \in]0;\pi[$.

Definition: *Apparent angle, ω:* The apparent angle is defined as the interior angle between two image lines resulting from perspectively projecting two junction lines onto an image plane. $\omega \in]0;\pi[$.

Definition: *Orientation of bisecting line, α:* The virtual image line arising from bisecting the two projected junction lines will be denoted as the bisecting line. The angle this line makes with the camera coordinate A-axis, figure 1, defines the orientation, α, (of the bisecting line). $\alpha \in [0;2\pi[$.

Definition: *Fixated Coordinate System, (FCS):* The Fixated Coordinate System is defined as an orthonormal frame having origin at the junction point, Q_F. The x-axis of the FCS is along the bisecting line of L_1 and L_2, the z-axis is along the normal of the plane spanned by the two lines and the y-axis is defined by the cross product of the two other base vectors, (see figure 1).

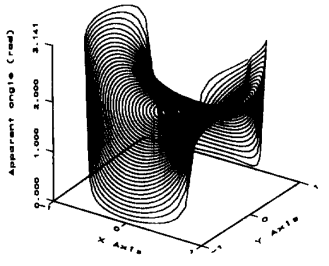

Figure 2: The apparent angle as a function of view point over the northern view semi-sphere. The true angle is $\pi/2$. Each point on the surface represents a three-tuple $< x, y, \omega >$, where x and y specify a view point in FCS coordinates according to the sphere equation, and ω is the apparent angle.

The analysis and arguments in this paper will cover the first four octants of the FCS only, assuming the z-axis is oriented so the initial view point (before moving) has a positive z-value. The view planning strategy we present, makes sure that no attempt is made to cross 'below' the junction plane.

If the general position of the camera relative to the FCS is denoted by spherical coordinates (d, θ, ϕ), it can be shown that the apparent angle is related to the true angle and the position of the camera by, ([1, 2, 3, 6]):

$$\tan(\omega) = \frac{2\cos(\theta)\sin(\Omega)}{(\cos^2(\theta)+1)\cos(\Omega) - \sin^2(\theta)\cos(2\phi)} \quad (1)$$

Noteworthy about the presented expression for the apparent angle is that 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 2 shows a plot of apparent angle as a function of view point for a particular true angle, namely 90 degrees. It is seen that the topology is that of a saddle surface; this is the case for all true angle values.

The two principle axes of the saddle-surface 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

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Figure 3: The black lines indicate a projected junction,- the white arrows are the image **positive speed** directions for **motion along bisector** and **motion across bisector**. **negative speed** is in the opposite direction of the arrows.

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 Motion Patterns

The two motion patterns involved in this study are defined over a common notion, where some *direction* in the image uniquely determines the parameters for a circle in space centered at the origin of the FCS.

Definition: *Motion along < direction >:* Let a view point be determined by spherical coordinates (d_0, θ_0, ϕ_0) in the FCS, valid at some instant in time, t_0. At t_0 it is assumed that the image plane is tilted so the origin of the FCS is in the image center, (fixation). If an image line passes through the image center, then a plane in space, Π, is spanned by the origin of the FCS and two points on that image line, transformed to FCS coordinates. Motion along the direction of the image line is defined as a circle in Π of diameter d_0.

Implementation of such trajectories without known, absolute motion, follows immediately from performing fixation. Each time fixation is performed, the image plane will be tangent to a sphere centered at the fixation point. By performing sequences of translation in the image plane, followed by fixation, the resulting trajectory will be a piecewise linear approximation to a planar circle in space.

Two motion patterns have been investigated, illustrated in figure 3:

Definition: *Motion along bisector:* Using the basic motion strategy, the bisecting image line of the junction is used as the direction. **Positive speed** is defined as translating in the chosen direction *away* from the junction point, (the image center).

Definition: *Motion across bisector:* Is defined similar to **motion along bisector**, only the chosen direction is rotated counter clockwise by $\pi/2$.

The resulting trajectory on the unit view sphere is a circle centered at Q_F, and it is the intersection of the plane Π and the unit sphere equation. A general vector function description of the resulting trajectories is given in [6]. Figure 4 shows examples of such trajectories. Please note, that the virtue of **motion along bisector** trajectories is that they pass through the yz-plane of the FCS in a direction which is close to perpendicular to that plane. Conversely, the **motion across bisector** trajectories pass through the xz-plane.

4 Location from visual events

When analyzing how the apparent angle and the orientation of the bisecting line evolve over time using the two motion patterns, it turns out that qualitative information about current camera position relative to the junction centered FCS can be obtained. It can be shown, that the combination of signs of the change in apparent angle, $\delta\omega/\delta t$, and change in orientation, $\delta\alpha/\delta t$, uniquely determines which octant, (one through four), the camera is in.

Figure 5 schematically presents the relation between octant and sign combinations. When comparing to the motion pattern trajectory plots in figure 4, it is seen that for both patterns a zero crossing in change in apparent angle (a visual event) marks the crossing through either the yz-plane or the xz-plane, depending on current motion pattern. A visual event can either be a positive to negative transition in $\delta\omega/\delta t$, or a negative to positive transition.

5 Basic Control Strategy

Based on the two motion patterns we can construct a simple control strategy, which guided by the visual events, moves the camera towards the canonical view point as introduced in section 1. The canonical view point, being a point on the FCS z-axis, has the property of resulting in a fronto-parallel projection of the

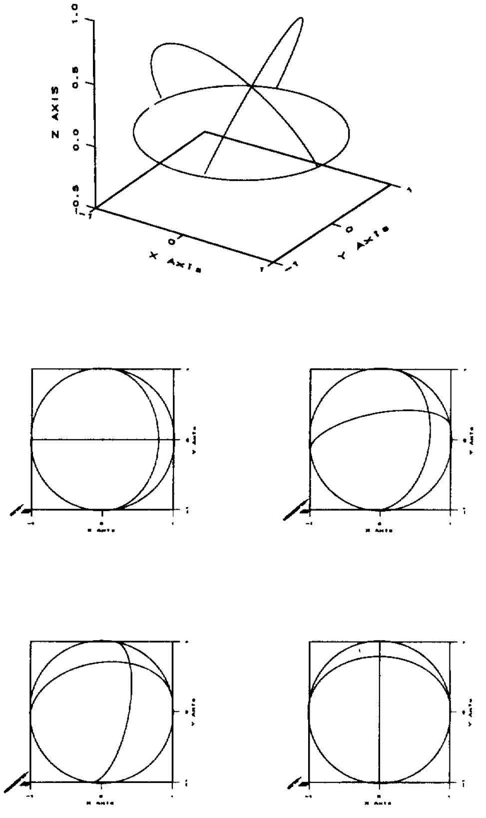

Figure 4: Top: perspective view of trajectories of both motion patterns given a starting point in the fourth octant, (where the trajectories cross). Lower four: top view of both motion pattern from different starting points in the first octant. All plot are in FCS coordinates, i.e., the viewed junction lies in the plane of the unit circle with legs symmetrically placed on both sides of the x-axis, (one in octant 1, the other in octant 4).

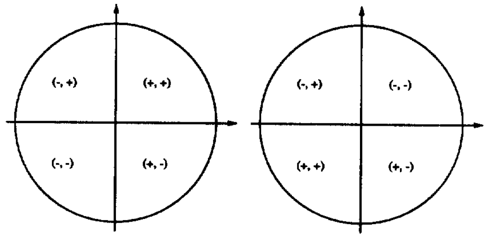

Figure 5: Knowledge about current position of camera obtainable from signs of change in apparent angle and orientation. The plus and minus signs in the parentheses indicate the sign of the change in apparent angle and orientation respectively. Left: **motion along bisector**, right: **motion across bisector**. The figures are valid for **positive speed**; reverse signs for **negative speed**.

plane spanned by the junction space lines, and thus the apparent angle is identically equal to the true angle.

The basic control strategy is a two-step process: 1) perform **motion along bisector** until a zero-crossing in change in apparent angle indicates the yz-plane is crossed. 2) perform **motion across bisector** until a similar event indicates a xz-plane crossing. Thus, the rationale behind the strategy is to exploit the coincidence of the principal axes of the apparent angle saddle surface with the x and y axes of the object centered FCS. In order to make intelligent choices of sign of speed for each motion pattern, the octant determining sign combinations of change in apparent angle and orientation can be exploited. In pseudo-code the basic control strategy can be formulated as in below, (where, e.g., $\omega(N)$ represents the apparent angle in frame N).

```
process Basic_Control_Strategy()
  fixate on chosen junction;
  grab frame no.  $N = 1$;
  compute $\omega(N)$;
  compute $\alpha(N)$;
  set motion along bisector;
  set positive speed;
  repeat
    translate using pattern & speed;
    fixate on junction;
    grab frame no.  $N = N + 1$;
    compute $\omega(N)$;
    compute $\alpha(N)$;
    compute $\Delta\omega(N)$;
    compute $\Delta\alpha(N)$;
```

```
  determine valid octant;
  if octant 1 or 4; $(\Delta\omega(N) > 0)$
     set negative speed;
until $\Delta\omega(N) = 0$

set motion across bisector;
if octant 1 or 2
   set negative speed;
else
   set positive speed;
repeat
  translate using pattern & speed;
  fixate on junction;
  grab frame no.  $N = N + 1$;
  compute $\omega(N)$;
  compute $\Delta\omega(N)$;
  if $\Delta\omega(N) < 0$
     set negative speed;
until $\Delta\omega(N) = 0$

assign $\omega(N)$ as true angle;
end Basic_Control_Strategy()
```

In the pseudo-code form the two sub-processes are represented as two repeat-segments terminated upon detection of a zero-crossing in change in apparent angle. In the first repeat-segment, **motion along bisector** is performed, initially with a default **positive speed**. If, in the course of moving with this pattern, visual events indicate a camera position in either octant 1 or 4, (positive x-coordinate), the speed is reversed, since we wish to direct the camera towards the yz-plane.

When a negative to positive transition in change in apparent angle is detected, **motion along bisector** is terminated. Based on the obtained knowledge about valid octants, a correct speed for **motion across bisector** can be chosen prior to initiating that motion pattern. I.e., if it turned out that the camera came to the yz-plane from octant either 1 or 2, (positive y), it is evident that **negative speed** must be chosen in order to get to the top of the view sphere. This reasoning is embedded in the statements between the two repeat-segments in the pseudo-code.

During the second and last sub-process, the event to look for is a positive to negative transition in change in apparent angle, indicating the arrival at a position close to the z-axis; i.e, the canonical view point. The angle in the image is identical to the true angle.

6 Experimental results

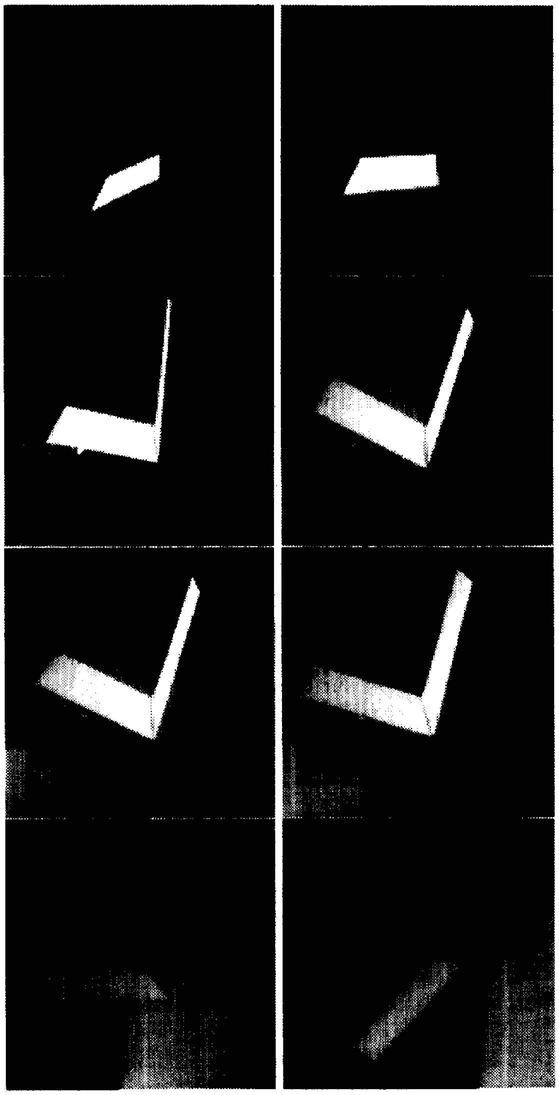

Figure 6: Eight frames picked from a sequence of 38 frames used in a typical experiment on real images. The frames are numbered left to right, top to bottom and correspond to frame 5, 10, 15, 19, 20, 24, 28 and 32 of the recorded sequence. The first 4 of the frames shown were taken during **Motion Along Bisector**, whereas the last 4 resulted from **Motion Across Bisector**. The control strategy terminated at an apparent angle of 90.7 degrees. Measured manually on the object the true angle was approx. 91.5 degrees.

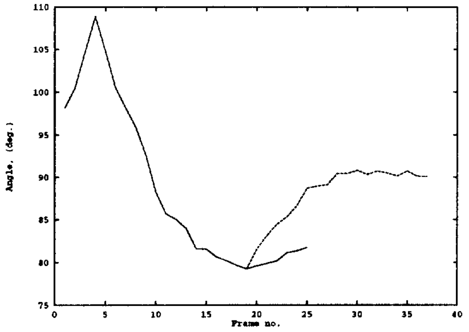

Figure 7: Apparent angle measurements from every frame in the presented experiment. A few additional frames after the negative to positive transition have been included to demonstrate, that the extremum was indeed global. The peak in the beginning marks the shift from **positive** to **negative speed**. The separation of the curves marks the strategy shift from **motion along bisector** to **motion across bisector**.

To demonstrate the presented view planning strategy figure 6 shows representative frames taken from a sequence recorded during a typical run of the strategy. A canny edge detector and a line linker has been used to process the images. The angle measurements presented in figure 7 were performed on the linked lines and fed to the presented algorithm along with the orientation of the bisecting line.

First the **motion along bisector** is engaged with the default **positive speed**. Only, since the initial view point is well inside the first octant of the FCS corresponding to the viewed junction, this combination results in an increase in apparent angle, (figure 7). The strategy automatically reverses the speed after a few frames, (delay due to smoothing of measured apparent angles). After the switch to **negative speed** the apparent angle starts to decrease and does so until a minimum is detected, forcing the strategy to shift to **motion across bisector**.

During the time where the apparent angle was decreasing, the orientation of the bisecting line was also decreasing, which (according to figure 5) is correctly interpreted as a camera position in the first octant. Thus, when **motion across bisector** is engaged, it is done using **negative speed** instead of the default, in order to approach the canonical view point.

7 Summary

We have addressed the problem of determining true angles in scenes containing static objects using view planning. The paper presented a simple two-step view planning strategy applying two motion patterns. 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, e.g., extrema in the apparent angle. Using these events, it is possible to avoid the use of positional feedback. Prototype experiments have demonstrated an accuracy in true angle determination within ± 2 degrees.

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