Danger estimation of the Robotic Travel Aid (RoTA) at intersection

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Abstract

We have been developing Robotic Travel Aid (RoTA) system since 1991 which guides the blind on a road or a sidewalk. One of the most difficult problems for RoTA is how to cross the intersection without a traffic accident. So, danger estimation for vehicles at the intersection is proposed in this paper. This method is implemented on an image processing system. The location, velocity, and the moving direction of a vehicle are measured by computer vision and its danger coefficient is evaluated. About 90% of vehicles in a T-shaped intersection have been correctly interpreted in danger judgments in real world scenes.

Keywords: Robotic travel aid; Danger estimation; Intersection; Image processing; Vehicle detection

1. Introduction

There are many outdoor mobile robots, for example VaMoRs [1], Navlab [9]. We have been developing Robotic Travel Aid (RoTA) system “HITOMI” since 1991 which guides the blind on a road or a sidewalk [6,7]. A photograph of “HITOMI” is shown in Fig. 1.

One of the most difficult problems for RoTA is how to cross the intersection without a traffic accident. To avoid accidents, RoTA estimates the vehicle arrival time to the intersection, and predicts its motion direction. Finally, it makes decision about when it should start crossing the intersection. RoTA should know the traffic rules and the behavior of the driver to predict the motion direction of vehicle as well as its arrival time. The motion and arrival prediction are probabilistic, not deterministic.

Research on mobile robots using traffic rules has been done by Takeno et al. [2]. They constructed traffic rules to achieve safe and smooth movement of robots. But the environment is restricted to indoors.

As part of a driver support system for motor vehicles on freeways, an obstacle recognition system was developed within the EUREKA project, PROMETHEUS. Regensburger and Graefe [8] developed a method of vehicle detection in real time for a straight, asphalt-paved road. They used a symmetry feature of an obstacle detection and recognition.

We developed a method of vehicle localization and velocity estimation [5]. We used a vehicle detection and tracking method based on a locomotion strategy, “sign pattern based stereo typed motion”. Our target environment is outdoors.

In this paper we present a theory of intersection crossing with the results of some experiments in real world.

2. Traffic rules and strategy

RoTA must decide by itself when it can start crossing. We assume that the intersection is without a traffic
signal. To explain the traffic rules of vehicles, a plot of an intersection without a traffic signal is shown in Fig. 2(a). The possible directions of a vehicle are shown in Fig. 2(b). To show the location of vehicle, the intersection area is divided into 12 sections numbered from S1 to S12. “A” denotes the location of RoTA in waiting for crossing. C1 and C2 show video cameras of RoTA.

2.1. Traffic rules of vehicle

We formulate the traffic rules including the behavior of the least careful driver. The traffic rules are as follows:

(1) Vehicles move along the left lane mark.

(2) Vehicles follow one of the typical trajectories. Fig. 3 shows the trajectory of the oncoming vehicle. Typical trajectories are four types of vehicles in the front, left, back and the right of the intersection.

(3) When a vehicle moves straight, the driver only pays visual attention to the front section. When the vehicle turns left, he pays attention to the forward and the left sections. When the vehicle turns right, the driver waits until all the straight-moving and right-turning vehicles pass by.

(4) When the trajectories of RoTA and the vehicle cross, the vehicle waits until RoTA passes by.

2.2. Traffic rules of RoTA

We consider that RoTA follows the same rules as the guide dog.

(1) RoTA moves along the left side of a road. The reason why the guide dog follows the left lane is not so clear, but among the eight Japanese guide dog training centers, six of them keep the left lane for moving, and the others keep both side lanes for moving.

(2) RoTA moves straight and turns left. Turning right is performed by moving straight, crossing the road and turning right.

(3) If RoTA stops at an intersection and detects a vehicle, it measures the vehicle’s distance, moving direction and speed. Finally, it estimates the vehicle’s danger coefficient. When the danger
3. Danger estimation

When the driver and the blind person keep the traffic rules perfectly, they will not meet with any accident. But as they often pay less attention to the right and the left sides of the intersection, they will occasionally have an accident.

There are some interesting works by Miura [3,4] which investigate the causes of the most probable accidents on the road. He showed that one of the greatest factors in the source of the accidents is the way the drivers observe the road. For instance, automobile drivers tend to look straight ahead: the proportion of the road surface in their visual field is smaller than that of motorcycle drivers. On the other hand, motorcyclists are apt to concentrate on the information of the near road surface. Therefore, they do not cover the distant foreground as widely. Another important source of accidents is the problem of underestimating the speed of oncoming vehicles by drivers and pedestrians.

According to the statistics of traffic accidents on the road in Yamanashi Prefecture in 1994, more than 48% of the accidents occurred at an intersection or near an intersection.

To avoid collision a danger estimate of a vehicle at intersection should be taken into account. As explained in traffic rule (2) of Section 2.2, RoTA can perform two types of motions: moving straight and turning left. Therefore, the danger coefficient of vehicles may change due to the RoTA motion. Three levels of danger coefficient have been defined in this work:

- 0 as safe
- 1 as warning
- 2 as risky

The robot can pass the intersection without any collision when the danger coefficient is in the safe state. When a vehicle is going to enter the intersection
momentarily, or if it has the same motion direction with that of the robot in leaving an intersection, then the danger coefficient becomes warning state. Thus warning means care should be taken during crossing the intersection. Finally, collision may occur if the danger coefficient is in the risky state. RoTA detects the location, \( s_i \), and the moving direction, \( r_j \), of the vehicle by a vision-based algorithm. The danger coefficient \( d_{ij} \) for a vehicle at \((s_i, r_j)\) for the RoTA in moving straight mode is shown in Fig. 2.

The danger estimates, \( f_1 \), for straight-moving RoTA and \( f_2 \), for left-turning RoTA are expressed as

\[
f_1 = S^T D_1 R,
\]

\[
f_2 = S^T D_2 R,
\]

where \( S^T \) is a unit vector that represents the location of the vehicle in the section. \( S_1 \) is represented by \( S = [1, 0, 0, \ldots, 0] \), and \( S_2 \) by \( S = [0, 1, 0, \ldots, 0] \). \( R \) is a unit vector representing the direction of the vehicle. For instance, direction 1 is represented by \( R = [1, 0, 0, \ldots, 0] \), 2 by \( R = [0, 1, 0, \ldots, 0] \). \( D_k \) (\( k = 1.2 \)) is a \( 12 \times 8 \) matrix of which element \( d_{ij} \) shows the danger coefficient of the vehicle moving at section \( S_i \) in direction \( j \). We call \( D \) the "danger matrix".

4. Algorithm

We implemented a real-time vehicle detection and tracking method based on the locomotion strategy "sign pattern based stereo typed motion" [5]. The sign pattern of a vehicle is the shadow area underneath which is different from any other parts of the asphalt road. The process is divided into five main sub-modules: lane mark detection, searching vehicles, confirmation, motion estimation and danger estimation.

4.1. Configurations of the sub-modules

The flow of the processing is as follows.

1. Lane mark detection:
   - window setup
2. Searching vehicles:
   - by vehicle underneath inf.
3. Confirmation:
   - line segment length

\begin{itemize}
  \item vehicle side operation
  \item symmetry operation
  \item homogeneity operation
\end{itemize}

(4) Motion estimation:
\begin{itemize}
  \item velocity estimation or
  \item vehicle width estimation
  \item distance estimation
  \item collision time estimation
  \item direction estimation
\end{itemize}

(5) Danger estimation:
\begin{itemize}
  \item Dangerness estimation
\end{itemize}

Fig. 4 shows the group of searching vehicle windows (Win1–Win7) at the intersection. In practice, when no intersection is in the way of the robot, the only window for detection and tracking vehicles is Win1. To set up this window, the left and the right lane marks are detected in the lane mark detection module. Then Win1, with the length of the road width, is established at the position that corresponds to a distance of 30 m from the robot on 2D image. Similarly, to set up the remaining windows, a priori knowledge of the intersection including that of stop lines and zebra marks are employed.

When the robot reaches the intersection, in each of the left and the right sides of the intersection (sections S3, S4, S7, and S8), three windows are set up to find vehicles' underneath areas.

To detect vehicles, a real-time search process is performed in each window successively. The detected underneath area in the search window is represented by the line segment \( L_s = (X_s, Y_s, X_e, Y_e) \). \((X_s, Y_s)\) and \((X_e, Y_e)\) denote the beginning and the end points of the line segment.
4.2. Tracking

Whenever a vehicle is detected in one of the defined windows, then a tracking process is activated. The motion direction of the vehicle and its danger coefficient are estimated during the tracking process. The tracking process is performed 40–50 times for a vehicle as it approaches, enters, and leaves the intersection. The distance, speed and the approach time of the oncoming vehicle to the intersection are evaluated during the tracking process.

A confirmation operation is performed during the visual investigation of vehicle appearance characteristics. The confirmation verifies the line segment in the search window through four operations: line segment length check, a vehicle side operation, a symmetry operation, and a homogeneity operation [5]. When the vehicle enters the intersection from the left or the right side then the symmetry operation and the right or left, vertical side operation are not performed. The reason is that the entire vehicle may not enter the visual field in the initial state of detection. In this case, the length of the line segment, the left or the right side operation and homogeneity are performed as in the confirmation process.

4.3. Approach time

To estimate the approach time during which an oncoming vehicle will reach the intersection, the distance between the robot and the vehicle, and the speed of the vehicle, are estimated. The distance, $D_i$, in the $i$th tracking window is found by

$$D_i = H(f - Y_i \tan \theta)/(Y_i + f \tan \theta).$$  \hfill (3)

$H$ and $Y_i$ represent the height of the robot and the ordinate position of the line segment, respectively. $\theta$ denotes the tilt angle of camera and $f$ is the focal length.

Similarly, velocity is given as follows:

$$V(t+1) = \frac{\Delta L \times D(t)}{L(t+1) \times \Delta(t)},$$  \hfill (4)

$\Delta L$ represents the change of the vehicle width in $\Delta(t)$ ms over two successive images, where $L(t+1)$ indicates the width of vehicle at time $(t+1)$. Fig. 5 shows an evaluation of velocity for three oncoming vehicles with constant velocities of 40, 30 and 20 km/h in the tracking process.

![Fig. 5. Result of vehicles velocity estimation.](image)

4.4. Motion direction estimation

To find the motion direction, the position of the moving vehicle is estimated by detecting the shadow underneath area of the vehicle during the tracking process. Then the motion vector $P_i$ is found and retained from time series of images.

To show the vehicle position on the image, the following ideas have been taken into consideration:

1. For an oncoming vehicle which moves in a straight route, the center position of the line segment $L_s$, as well as its angular motion, are found in the time series of images. In this case the center position of the vehicle $(X_{\text{cen}}, Y_{\text{cen}})$ is determined by the average value of $X_{\text{cen}} = \frac{1}{2}(X_s + X_e)$, and $Y_{\text{cen}} = (Y_s = Y_e)$ of the line segment.

2. For an oncoming vehicle which turns left or right at the intersection, the underneath area of the vehicle is represented by two line segments $L_s$ and $L_t$. These are represented by $L_s = (X_s, Y_s, X_e, Y_e)$ and $L_t = (X_c, Y_c, X_b, Y_b)$. $L_s$ indicates the line segment of the vehicle’s front while $L_t$ shows that of the vehicle’s side. When the vehicle makes a turn at the intersection, then the length of $L_s$ gradually decreases while that of $L_t$ smoothly increases. The position of the vehicle is found by
the projection of line segments $L_s$ and $L_t$ on the horizontal line $(X_s, Y_s, X_b, Y_t)$.

(3) A vehicle which enters the intersection from the left or the right side is detected and located using $L_s$, and a vertical line segment $L_y$.

These indicate the vehicle's side at the beginning of its maneuver. When the vehicle makes turn the same process as (2) is performed.

The time series of images, the angular motion of an oncoming vehicle, a rigid object, decreases (increases) smoothly when it turns right (left) at the intersection in time series of images. Similarly, the angular motion has almost no change when the vehicle moves along the left lane mark. When the vehicle's position as well as its motion direction are found then its location and the motion direction matrices are set up.

5. Experimental results

5.1. Vision system and input data

Video camera C1 is set at 2.5 m in front of a T-shaped intersection and 1.0 m in height with 14° of depression angle. More than hundred vehicles passed the intersection within 15 min of a video tape recording. For T-shaped intersection, danger matrix $D_1$ is transformed into a $9 \times 8$ matrix excluding columns corresponding to S7 and S8.

The vehicle detection algorithm is implemented on a one-board image processor (H15500 (MC68040, 25 MHz) by TAKANO Co. Ltd.). Tracking a vehicle is performed at video rate (33 ms). The danger coefficient is measured while the vehicle passes the intersection within 3–4 s.

5.2. Results

An example of three sampled scenes is shown in Fig. 6. In the right side of the display six parameters are shown: "TIME" indicates the processing time of one frame. "Moving Car" shows the result of the moving object identification process. "DIST" is the measured distance of the vehicle from the video camera in meters. "Speed" shows the measured velocity of the vehicle in km/h. "AP_TIM" indicates the vehicle's arrival time at the intersection. The trajectory of

<table>
<thead>
<tr>
<th>Course</th>
<th>Vehicles</th>
<th>Correct</th>
<th>False</th>
</tr>
</thead>
<tbody>
<tr>
<td>1S</td>
<td>36</td>
<td>30</td>
<td>6</td>
</tr>
<tr>
<td>1R</td>
<td>16</td>
<td>15</td>
<td>1</td>
</tr>
<tr>
<td>3L</td>
<td>23</td>
<td>22</td>
<td>1</td>
</tr>
<tr>
<td>3R</td>
<td>30</td>
<td>28</td>
<td>2</td>
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<td><strong>Total</strong></td>
<td><strong>105</strong></td>
<td><strong>95</strong></td>
<td><strong>10</strong></td>
</tr>
<tr>
<td><strong>Rate</strong></td>
<td><strong>100%</strong></td>
<td><strong>90.5%</strong></td>
<td><strong>9.5%</strong></td>
</tr>
</tbody>
</table>

1S: moving straight from S1; 1R: turning right from S1; 3L: turning left from S3; 3R: turning right from S3.

the vehicle is shown at the bottom. Finally, the danger coefficient of the vehicle shows the intersection status: safe, warning, and risky.

By looking at the display we judged the status given by the system. The performance of the system for 105 vehicles is shown in Table 1. Course shows the trajectory of the vehicle, the first number shows the starting section and the second character shows its actions:

- S: straight-moving
- R: right-turning
- L: left-turning

Among 10 misjudgments, one was caused by a trajectory other than typical ones. Another was caused by the mistracking of an image of a vehicle too large to process at video rate. The remaining eight misjudgments were caused by two or three vehicles in successive running at less than 20 m apart. The vision system is successful in tracking the first vehicle, but often fails in detecting the second vehicle.

6. Conclusions and future research

To make a locomotion strategy at an intersection, sign patterns of a vehicle as a vehicle model, the traffic rules of vehicles, and the robot locomotion strategy were considered. A danger estimate for vehicles which help a robot to cross the intersection was proposed. To express the danger coefficient for a vehicle, a danger matrix was defined. The number of danger coefficient matrices depends on the number of robot motion strategies at the intersection, e.g. straight-moving or left-turning motion. The danger measuring method was implemented on a real-time
vision system. Experimental results showed the feasibility and validity of the method.

In our experiment, scenes were restricted to T-shaped intersections because our TV camera lens system did not support a wide area and the speed of the camera platform was slow. We have been developing two-lens system (wide and zoom area lenses).

In the future we are planning to extract robustly vehicles against the noise and variability associated with dynamic worlds.

References


