MVA '92 IAPR Workshop on Machine Vision Applications Dec. 7-9,1992, Tokyo

Tracking of Vehicles at an Intersection by Integration of Multiple Image Sensors

Shuichi NISHIO

NTT DATA COMMUNICATIONS SYSTEMS CORPORATION
66-2 Horikawa-cho, Saiwai-ku, Kawasaki, Kanagawa 210, Japan

Yuichi OHTA

Institute of Information Sciences and Electronics, University of Tsukuba
Tsukuba Science City, Ibaraki 305, Japan

Abstract *- This paper describes a vehicle tracking system which detects and tracks vehicles passing through an intersection using information obtained from multiple image sensors. The proposed system is based on multiagent model to actualize a distributed and concurrent tracking. The system has two main components, sensor agents and vehicle agents. By means of communication between sensor and vehicle agents the trajectories of moving vehicles are detected. Making use of the visual information about the shape of a vehicle and some features, size and color, which detected by sensor agents and a priory knowledge on vehicle motion, each vehicle agent autonomously tracks the trajectory of a vehicle. Additionally, a 3-D model-based tracking and multi-view observation from multiple image sensors lead to easier estimation of 3-D trajectory of a vehicle.*

1. Introduction

With the increase of traffic jam and accidents at intersections, the development of new traffic monitoring system using computer vision techniques is desired. The output from such a traffic monitoring system should include the trajectories of moving vehicles together with the type of vehicles (e.g.sedan, bus). There are various ways which extract vehicle trajectories from image sequence. Most of those methods, however, assumed that a whole road or intersection is visible from a single image sensor. In actual situations, multiple image sensors are necessary to cover an intersection, and vehicles must be tracked as they pass through one image to another.

A major problem with vehicle tracking using multiple sensors is identification of vehicles observed on different sensors. This has been discussed as a distributed sensing problem in research of distributed artificial intelligence rather than in computer vision. The main issues of the discussions are how to construct the network of sensor agents and how to reduce the cost of communication between agents. Unfortunately, because they assumed acoustic sensors, only a little information, that is, the power of the sensed data and the location, could be used for identification of vehicles. On the other hand, fortunately, the use of image sensors brings much efficient information for the identification. In fact, each vehicle can be detected together with visual information, such as shape, size and color. The information could be used for identification of vehicles on different image sensors and also on successive image frames. However, it has not been discussed enough how to manage and utilize the visual information, especially for identification of vehicles on different image sensors.

In this paper we propose a vehicle tracking system which detects and tracks vehicles passing through an intersection using information obtained from multiple image sensors. The proposed system is based on multiagent model to actualize a distributed and concurrent tracking. The system has two main components, sensor agents and vehicle agents. By means of communication between sensor and vehicle agents the trajectories of moving vehicles are detected.

2. System Overview

Fig.1 illustrates a simplified example of vehicle tracking system using multiple image sensors. In this case, three image sensors cover a T-intersection, and each image sensor observes a pre-allocated area with some overlapping between adjacent image sensors. It is not practical to analyze all images obtained from multiple image sensors by a single agent because of huge processing cost for vehicle detection and tracking. The task of vehicle tracking using multiple image sensors involves the concurrence and coordination of multiagent in the image sensor network.

In conventional methods, each sensor agent is responsible for a portion of the intersection and obtains partial tracks. All agents works in parallel and exchange their partial results to converge on complete trajectories of vehicles (see Fig.2-a). As described before, assuming the use of the acoustic sensors, a vehicle is detected just as a point which represents the location of the vehicle. Thus, only a little in-

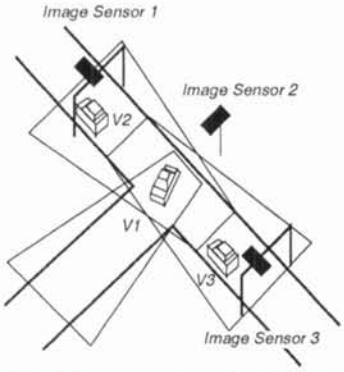


Fig.1 An example of vehicle tracking system using multiple image sensors

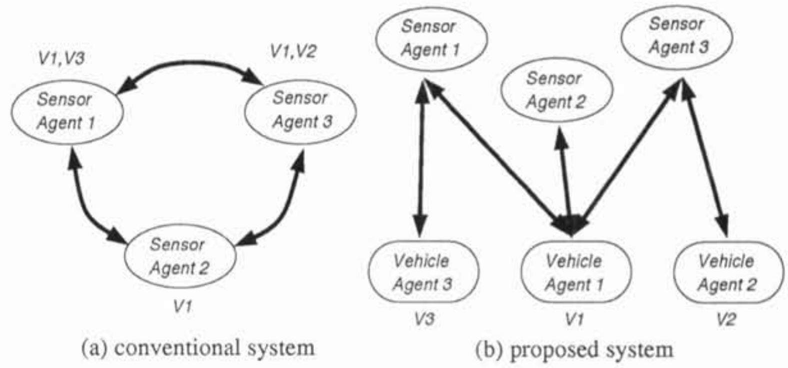


Fig.2 Conceptual constitution of the vehicle tracking system based on multiagent model

formation could be used for the identification of vehicles.

The architecture of the proposed system is based on the following considerations.

(1) The visual information about the shape of a vehicle and some features, size and color, which characterize its appearance in images should be used for tracking. To actualize this, vehicle agents are delegated to keep watch on detected vehicles. Making use of the visual information detected by sensor agents and a priory knowledge on vehicle motion, each vehicle agent autonomously tracks the trajectory of a vehicle.

(2) Since the main task of a sensor agent is to verify the locations of moving vehicles based on the information supplied from the vehicle agents only in a pre-allocated area, the communication between other sensor agents is not necessary. This condition brings the flexibility in the configuration of image sensors.

(3) A 3-D model-based tracking method and multi-view observation from multiple image sensors lead to easier estimation of vehicle type and resolution of occlusion.

Fig.2-b shows a conceptual constitution of the proposed system. Once a vehicle agent is delegated, the vehicle agent predicts a provisional position and direction for the vehicle in the next frame taking care of its past trajectory. Then the vehicle agent announces the hypothesis to all sensor agents with the visual information. The hypothesizes are verified by sensor agents. Finally, a complete trajectory of the vehicle through the intersection is reported by the vehicle agent.

In the following sections 3 and 4, we will describe the functional properties of sensor and vehicle agents, respectively.

3. Sensor Agents

As described in the previous section, the main task of a sensor agent is to detect candidates of moving vehicles in a pre-allocated area. In the proposed system, each vehicle is handled as a 3-D object, and the position and the trajectory are defined in a 3-D world coordinate system. The goal of sensor agents is to find the three dimensional position and direction of the vehicles in every instant. Each sensor agent tries to fulfil its goal, and knows the way how to break down the goal into primitive tasks for execution.

The task of a sensor agent is decomposed into four subtasks, vehicle detection, vehicle recognition, vehicle localization and delegation of vehicle agents .

3.1 Vehicle detection

A sensor agent first tries to detect regions corresponding to moving vehicles on each frame of the image sequence. There are many methods for detecting moving objects. We have used a picture differencing method which subtracts the current image from a reference image. This method has an advantage that even if vehicles become stationary they can be detected. In fact, there are many cases that vehicles become stationary at an intersection because of stop signals or traffic jams.

Vehicle detection are executed not only in the area of interest requested from vehicle agents but also in the whole observation area to find new vehicles.

3.2 Vehicle recognition

Sensor agents share the task to determine the type of vehicles with vehicle agents. Our system has 3-D wireframe models of various vehicle types. Fig.3 shows examples of the wireframe models. It is difficult to determine the type of a vehicle uniquely by a single view. However, a set of widely separated image sensors would give a rich information on the shape of vehicles. In our system each sensor agent independently calculates a certainty score for each model based on a silhouette matching technique. Certainty scores are sent to a vehicle agent and combined.

3.3 Vehicle localization

For each vehicle, sensor agents determine the geometric transformation from 3-D world coordinates to 2-D sensor

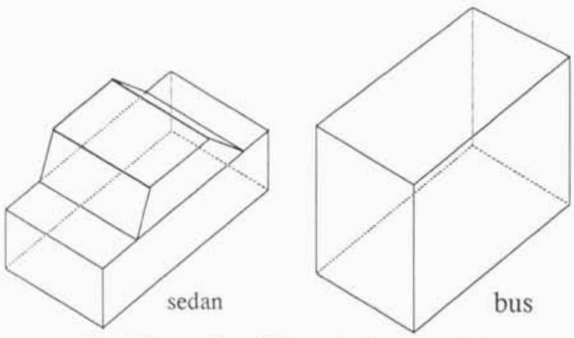


Fig.3 Examples of 3-D wireframe model

coordinates, and it is called a model fitting. Using the carefully defined image sensor and ground plane geometry, and given a position, direction and size of a 3-D object model, the model can be easily projected onto the 2-D image, however, it generally costs computational power to determine so many variables with no restrictions. We developed a model fitting method employing three restrictions concerning the vehicle motion, as follows.

(1) The ground plane is assumed to be flat. Additionally, we assume the geometry of image sensors against the ground plane is known. The location of a vehicle is defined in terms of its coordinate on the ground plane.

(2) A vehicle is assumed to be facing to the direction of motion. The orientation of the 3-D model of a vehicle on the ground plane can be uniquely determined by the direction of its 2-D motion on the image.

(3) The width of a vehicle is rather constant compared to the length or height. So we assume that the width of 3-D model is constant. This reduces the number of variables concerning the size from 3 to 2.

Using these assumptions, only four independent variables should be determined based on the shape information (position : 2, size : 2).

3.4 Vehicle agents delegation

Once a sensor agent detects a new candidate of moving vehicle, then a new vehicle agent is delegated with the visual information of the vehicle, that is, the position and direction on the ground plane, the vehicle type with its certainty score, the size and color. If there is an existing vehicle agent corresponding to that vehicle, sensor agent will send the visual information to the vehicle agent without generating new agent.

4. Vehicle Agents

As described in section 2, the main task (goal) of a vehicle agent is to track the allocated vehicle as long as it travels in an intersection. Each vehicle agent tries to fulfil its goal by means of the commutation between multiple sensor agents.

The task of a vehicle agent is decomposed into three subtasks, position prediction, inquiry, and information analysis.

4.1 Position prediction

Each vehicle agent predicts the position and direction for the allocated vehicle in the next time according to its past trajectory. We adopt a 2nd-order polynomial expression for the approximation of the trajectory.

4.2 Inquiry

After the position in the next time has been predicted, each vehicle agent will announce the expected position to all sensor agents. At that time, the area of interest in the 3-D world is set as an attention box as illustrated in Fig.4. When the attention box or its portion is visible to a sensor agent, the sensor agent will accepts the inquiry message of the vehicle agent and requests the vehicle agent to send the farther information concerning the vehicle. If no sensor agents accept the inquiry message, the vehicle agent recognizes that the vehicle traveled out from the intersection, and it autonomously disappears.

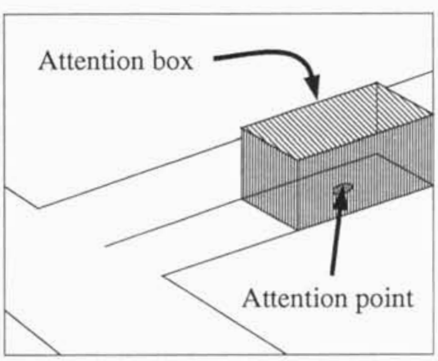


Fig.4 An attention box

4.3 Information analysis

According to the answer messages of the verification from sensor agents, vehicle agents will change their behavior as follows.

[*Case 1*] When only one sensor agent returned the successful message, the vehicle agent will record the position of the vehicle. If new certainty score of the vehicle type is higher than the score recorded in the past, then the visual information will be renewed.

[*Case 2*] If two or more sensor agents returned the successful messages, then the vehicle agent will combines the reported positions according to the certainty scores.

[*Case 3*] If no sensor agents returned the successful message, then the predicted position and direction are adopted.

5. Experimental Results

All components have been implemented on a SPARC station. However, they are not combined as a multiagent system yet. Here, we present intermediate results from preliminary experiments for the confirmation of the performance of each component with real traffic scenes.

Fig.5 shows some examples of the model fitting. Fig.6 shows the trajectories obtained by using three image sensors.

6. Conclusion

In this paper we described a design of a vehicle tracking system which detects and tracks vehicles passing through an intersection using information obtained from multiple image sensors. The following two features characterize the proposed system. First, the trajectories of moving vehicles are detected by means of communication between sensor and vehicle agents . Second, 3-D model-based tracking method is used to estimate 3-D trajectories.

In father, we will implement the system on a distributed processing environment to verify the advantage of the proposed system.

Acknowledgments

We wish to thank Mr.Y.Tanaka, senior executive manager of Development Headquarters, Dr.H.Arakawa and Dr.S.Fukami for their encouragement. We also acknowledge the help of Mr. M.Sakai and Mr. T.Kagehiro for taking traffic scene image data.

References

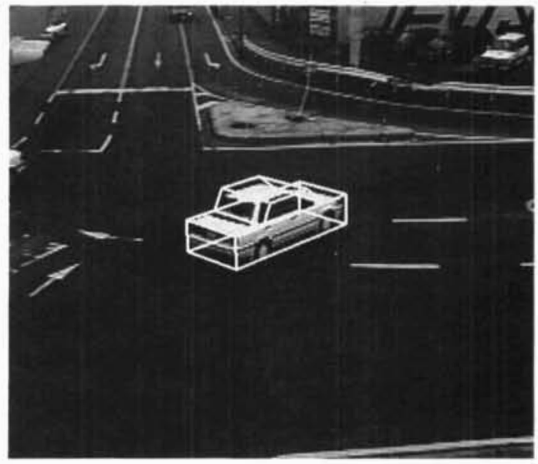
[1] Edited by A.H.Bond and L.Gasser, " Readings in Distributed Artificial Intelligence ," Morgan Kaufmann Pub.Inc. (1988).

[2] A.D.Worrall, R.F.Marslin, G.D.Sullivan and K.D.Baker, " Model-based Tracking ," Proc. BMCV'91, Glasgow, pp.310-318 (1991).

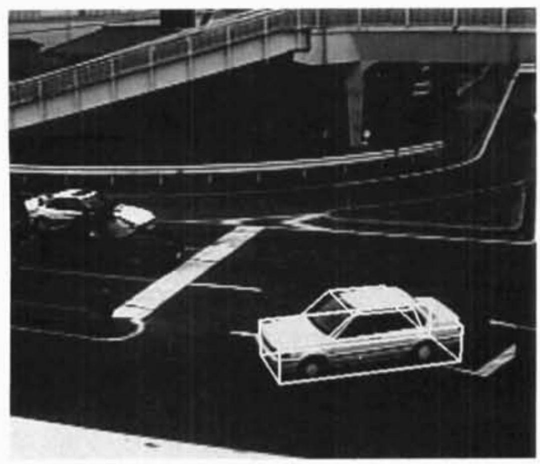
[3] D.C.Hogg, G.D.Sullivan, K.D.Baker and D.H.Mott, " Recognition of vehicles in traffic scenes using geometric models ," Proc.IEE 1st.Conf. Road Traffic Data Collection, London, pp.115-119 (1984).

[4] M.Yachida, M.Asada and S.Tsuji, "Automatic Analysis of Moving Images," IEEE Trans. PAMI. vol.3, no.1, pp.12--19 (1981).

[5] A.T.Ali and E.L.Dagless, " Vehicle and Pedestrian Detection and Tracking," Proc.IEE Colloquium on Image Analysis for Transport Applications (1990).



(a) on image sensor A



(b) on image sensor C

Fig.5 Fitted model on different image sensors

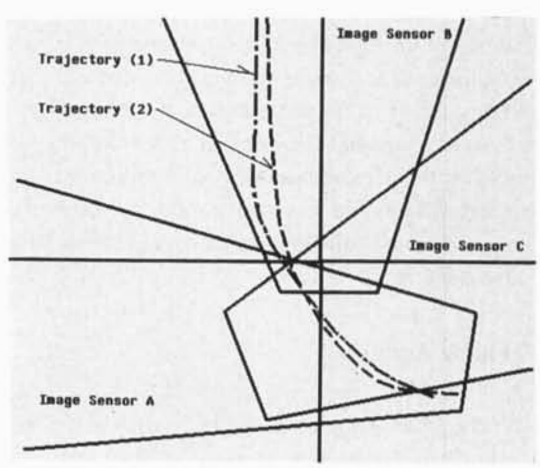


Fig.6 The trajectories obtained by using three image sensors