Adaptive Traffic Signal Control System Using Camera Sensor and Embedded System

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***Abstract*—Adaptive traffic signal control system is needed to avoid traffic congestion that has many disadvantages. This paper presents an adaptive traffic signal control system using camera as an input sensor that providing real-time traffic data. Principal Component Analysis (PCA) is used to analyze and to classify object on video frame for detecting vehicles. Distributed Constraint Satisfaction Problem (DCSP) method determine the duration of each traffic signal, based on counted number of vehicles at each lane. The system is implemented in embedded systems using BeagleBoard^{TM}.**

***Keywords*—Traffic Signal Control System, Vehicle Detection, Vehicle Counting, Principal Component Analysis, Distributed Constraint Satisfaction Problem**

I. INTRODUCTION

Traffic is the main source of the city life because it is the backbone of capital flows, logistics, information, and various activities which plays an important role in social stability, development, and improvement of community. Without an appropriate traffic signal control system, the possibility of traffic congestion will be very high and hinder people's life in urban areas [1]. Most of traffic signal control systems are still using stand-alone system, where each traffic signal duration has been determined by an officer. This causes the traffic signal unable to adapt to the traffic density, which often leads to the accumulation of vehicles and traffic congestion [1]. Economic losses due to traffic congestion in Jakarta based on research of Yayasan Pelangi in 2005 was estimated up to Rp 12,8 trillion per year, including loss of time, fuel costs, and health costs. Meanwhile, 2004 SITRAMP II showed that if there is no improvement with the transportation system until 2020, the estimation of economic losses would reach Rp 65 trillion per year [2]. So, the information acquisition of traffic density is an important issue.

Jakarta and other big cities in Indonesia currently have quite a lot of CCTV cameras installed at the intersections [3]. Nevertheless, the camera is merely monitoring the situation and does not contribute to traffic signal control system. By using computer vision techniques, the use of camera offer an alternative way to obtain information of the traffic density. Video-based camera system is more sophisticated and powerful because the information from the successive and interconnected video image can be used for vehicle detection, tracking, and classification [1]–[2].

There are several adaptive traffic signal control systems that have been developed in several countries, such as SCOOT [4], SCATS [5], OPAC [6], and RHODES [7]. Most of the systems uses devices that quite large, expensive, and difficult to be installed. So, the expected result of this research is to produce a prototype of adaptive traffic signal control system in accordance with the needs of the people of Indonesia that is cheaper, smaller, and has a smart system.

Based on the above background, we conduct research and development of adaptive traffic signal control system that adjusted with the 1993 Indonesian Government Regulation No. 43 about the Infrastructure and Road Traffic (PP No. 43 Tahun 1993, tentang Prasarana dan Lalu Lintas Jalan). The method was developed utilizing input from camera and using soft computing approach to obtain information on traffic density, namely Principal Component Analysis (PCA) algorithm. Whereas to calculate the time of each traffic signal at the intersection, we use the method of Distributed Constraint Satisfaction Problem (DCSP). This method is also used for multi-intersection traffic signal control system, where the neighboring intersection can communicate with each other to share datas and collaborate.

II. THE ARCHITECTURE OF TRAFFIC SIGNAL CONTROL SYSTEM

To discover the traffic situation, the system will be developed utilizing the camera at intersections, as shown in Figure 1. (i) Video from camera then will be processed using Principle Component Analysis (PCA). PCA method is used to obtain the main components of the detected vehicle features that then will be classified. (ii) Traffic data at the intersection is processed using the method of Distributed Constraint Satisfaction Problem (DCSP) to generate the best duration for the traffic signal under the circumstances. DCSP method allows the setting of multi-intersection traffic signal control system that can reduce the possibility of vehicle accumulation at points of congestion. To simplify, accelerate and provide results that can be applied, we develop the prototype of adaptive traffic signal control system using camera as input sensor for real-time traffic information acquisition and BeagleBoard^{TM} as traffic engine for data processing.

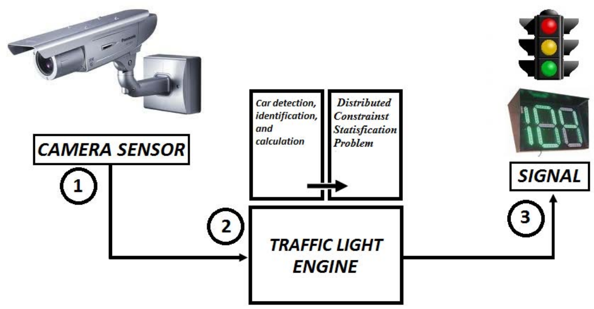

Figure 1. Architecture Diagram of Traffic Signal Control System.

III. Method

A. State of The Art

Real-time data on traffic density, especially in big cities is very important for effective traffic signal control system and its management. In addition, the information of traffic density can be used to estimate travel time from one location to another and also recommendations for alternative routes [8].

Detection of moving objects including vehicle, people, and others in the video can be achieved by three main approaches; temporal differences, optical flow, and background extraction. In the temporal differences approach, moving object can be detected from the successive and interconnected video image [9-15]. However, this approach has several limitations such as the homogenity of the image and level of effectiveness that depends on the speed of movement of objects in the video image [16]. Optical flow approach was developed to obtain modification of an effective background; this method is based on detecting differences in light intensity [16]. However, the changes of light due to weather or sunlight can decrease the effectiveness of this method. Moreover, this method is also inefficient in terms of computing [16]. The third method, the extraction of background, is the most frequently encountered in literature of moving object detection and identification [16-19].

In the background extraction, background can be static, where the initial background was specified earlier and used on the entire process, or can be dynamic, where the initial background changed dynamically based on external changes that occur, such as weather. Ordinary static background is not effective in many applications so that many methods using dynamic background extraction. In [20], background is detected dynamically by using a dynamic selection method restriction. In [21], landmark-based method and the method of BS & Edge used to eliminate shadows on the image.

The technique used to detect vehicles in daytime conditions has been comprehensively reviewed in [22]. Most of the features used for the detection of vehicles during the day have limited use in dark conditions or at night [23]. In previous studies, the research team has developed a vehicle detection algorithms and calculation that effective only during the day but less accurate at the night [24]. In some literature [25, 26], have been shown how to detect moving vehicles at night. The main lights are used as the main features of the vehicle and extracted by morphological analysis [23, 25].

B. Traffic Signal Control System

Traffic signal control system is one of the most active research area in intelligent transportation system (ITS) research, because this research makes a direct contribution on efficiency of urban transportation system [27]. Over the years many researchers conducting research in the optimum control of traffic signal. Webster [28] has developed equations for the optimum cycle time and the control of green light phase, which are the basis of static traffic signal control system that has been widely used. At the current developments, computational algorithms are used to get an effective traffic signal control system where its main target is to minimize the waiting time of vehicle at intersection [29]. Many soft computing approaches have been widely used by researchers such as fuzzy logic [27, 30, 31], neural network [32], and genetics algorithm [33]. In addition, coordinated traffic signal approaches [34, 35, 36] also has been widely used by researchers including one of our study which have been implemented [36-39].

There are three important components or parameters in the traffic signal control system as follows [40].

1. Cycle times: Period of one traffic light cycle, to determine the length of each periode of red, yellow, and green light.
2. Green split: The length of green light period on each road at the intersection.
3. Offset: The relative time difference between the start of the green light at the intersection and the start of the green light at the neighbouring intersections.

IV. Algorithm

A. Principal Component Analysis (PCA)

Principal Component Analysis (PCA) involves a mathematical procedure that transforms a number of possibly correlated variables into a smaller number of uncorrelated variables called principal components. The first principal component accounts for as much of the variability in the data as possible, and each succeeding component accounts for as much of the remaining variability as possible.

Based on theoretical concepts, PCA is used for finding the most appropriate computational model to describe an object by extracting the most relevant information contained in the object. Eigenvector in the PCA is an approach where a small group of characteristics of the object image is used to describe the variation between the images of certain objects, such as the type of car, mini-buses, buses, trucks, and other. The goal is to find the eigenvector of covariance matrix distribution which is stretched by training using a series of pictures of objects. Then, each image object is represented by a linear combination of this eigenvector. The detection is done by projecting the image or new image to the subspace which runs by the eigenvector and then classifies vehicles by comparing its position in space objects with a particular position. Mathematical equations of PCA algorithm can be found in [41].

B. Distributed Constraint Satisfaction Problem (DCSP)

Distributed Constraint Satisfication Problem (DCSP) is the search for the value of the distributed variables of a problem that the results are obtained from a corresponding combination

[42]. Such combination problems are found in the field of artificial intelligence and pattern analysis, including the scheduling and planning problem. Constraint Satisfaction Problem (CSP) is defined as V, D, and C, where V is the set of variables, D is a set of values to be inserted into the variable, and C is the set of constraints required by the variable. A distributed CSP, referred as DCSP, is the CSP that its variables and their constraints are distributed among many agents. DCSP consists of:

- A set of agents, 1,2, ..., k,
- A set of CSP, P1, P2, ... Pk,

where Pi is a property of agents i and consists of: (a). The set of local variables whose value is controlled by agent I; (b). The set of intra-agent constraints, each agent is defined through the local variable I; (c). The set of inter-agent constraints, each agent is defined through the local variable i and local variables of other agents.

To overcome the problem of congestion at each intersection, the whole system is defined as a multiagent system that represents the CSP and then developed into a DCSP. Each traffic information is distributed across each intersection agent. So, each intersection will be able to decide the duration for traffic signal from the DCSP algorithm [42].

V. Experiment and Result

A. *Prototype Implementation*

Broadly speaking, the architecture of a traffic signal control system can be divided into three major components as shown in Figure 2**.** The first component is the video camera sensor. This component has a function to capture images of traffic condition in every intersection on each lane. Decision made by Traffic Engine depends on the density of the traffic which the condition is known from the result of the captured image through this component. We use Logitech QuickCam^{TM} Connect 1,3 MegaPixel as the video camera sensor.

The second component is the Traffic Engine. This component acts as the brain of every decision to be made. After the first component gave the data in the form of image of traffic condition, this component will process the image to determine how many number of vehicles in each lane intersection. After that, the data will be counted with the Distributed Constraint Statisfication Problem (DCSP) in which resulting the best time for traffic signal. At the early stage of experiment, we use DELL™ XPS M1330 with specification: Core 2 Duo 2,5 GHz processor, 3 GB memory RAM, nVidia GeForce Go 8400M GS graphic adapter, and Linux Ubuntu 9.10 Karmic Koala Operating System. At the later stage of experiment, we use BeagleBoard™ with specification ARM Cortex-A8 core 720 MHz processor, 256MB memory RAM, and Linux Armstrong operating system.

The result of DCSP calculation generated by the traffic engine will be sent into the last component, which is the traffic signal. The traffic signal which is integrated with the traffic engine will give signals correspondently to the data that had been processed. At the experiment, we made a microcontroller with AVR ATmega32 and four miniature of traffic signal. Microcontroller is used to translate the result of traffic engine calculation into the digital signal which will be presented by the miniature of traffic signal consist of LEDs colored red, yellow, and green and three seven segment.

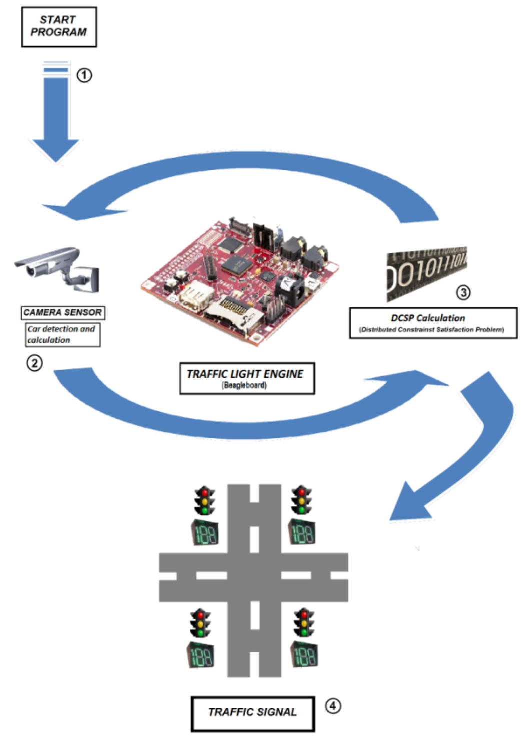

Figure 2. Architecture Implementation of Traffic Signal Control System.

Figure 3. Logitech QuickCam^{TM} Connect, DELL^{TM} XPS M1330, and Beagleboard^{TM}.

B. *Prototype Components*

The prototype consist of several components, including web camera, main controler (BeagleBoard™), and traffic signal controller. The traffic signal controller is actually the subsystem of the overall system that is made. The controller that is being used in the system is AVR ATmega32 microcontroller. The task of this system is to receive data from the system main controller. After receiving data from the main controller, the subsystem has to give the red or green signal at each lane and also the time duration of each signal.

The parts of traffic signal controller subsystem consist of controller board and four traffic signal boards which has red, yellow, and green light, and also three seven segment to display the time counter on a lane.

1. Controller Board

This board contains a set of minimum system with AVR ATmega32 microcontroller. This system has a variety of electronic components, including resistors, capacitor, LED (indicator), the transistor crystal, etc. This board also has an AVR ATmega8 that acts as BCD which has a role to convert the decimal data sent by the main controller AVR ATmega32 into binary to be displayed on the seven segment as a counter.

2. Traffic Signal Board

This board consist of traffic signal and three seven segment. This board acts as a traffic signal.

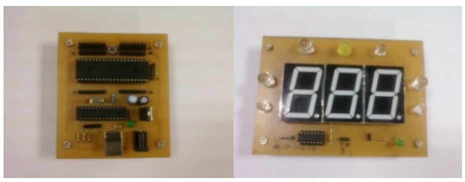

Figure 4. Controller Board and Traffic Signal Board.

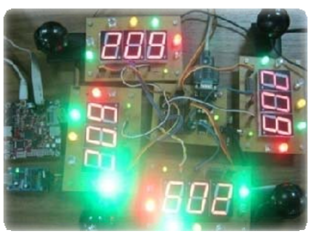

Figure 5. Prototype of Traffic Signal Control System.

Screenshot of the running program can be seen in Figure 6. with the experiment results in Table 1. Experimental result shows that the results of vehicle detection depends on the weather conditions and camera viewpoint. From the 8 variations of existing video, PCA has good performance on vs0.avi, vs1.avi, and b.avi with the accuracy level above 50%. Whereas 5 other videos provide a low level of accuracy due to weather conditions and camera viewpoints that are not appropriate. Video a.avi and z.avi were taken at night (dark weather), so that PCA is more difficult to detect the vehicle, related to the level of light on the video. Video d.avi, vs2.avi, and vs3.avi were taken with camera viewpoint from the side (not from the front), so that PCA is more difficult to detect the vehicle, related to the form of the vehicle on the video compared to trained vehicle data of the program.

Figure 6. Screenshot of the running program.

TABLE I.
RESULTS OF VEHICLE COUNTING BY USING OUR ALGORITHM UNDER DIFFERENT CONDITIONS

Weather and Traffic Condition	Number of Vehicle (by Manual)	Number of Vehicle (by Our Algorithm)	% Accuracy
At Sunny Day in Heavy Traffic (vs0.avi)	87	115	67.82
At Rainy Day in Normal Traffic (vs1.avi)	58	56	96.55
At Night, Side view (a.avi)	207	82	39.61
At Night, Front view (z.avi)	50	18	36.00
At Sunny Day, Front view (b.avi)	125	71	56.80
At Sunny Day, Side view (d.avi)	80	20	25.00
At Sunny Day, Side view (vs2.avi)	60	1	1.67
At Sunny Day, Zoom view (vs3.avi)	46	9	19.57

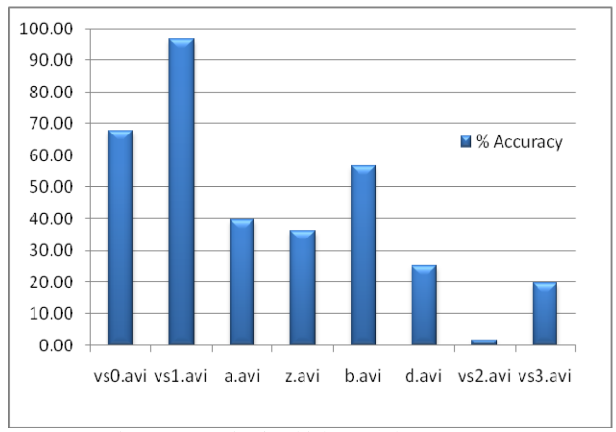

Figure 7. Graph of Vehicle Counting Accuracy.

Figure 8. Captured video frame of vs0.avi, vs1.avi, and a.avi.

Figure 9. Captured video frame of z.avi, b.avi and d.avi.

Figure 10. Captured video frame of vs2.avi and vs3.avi.

VI. CONCLUSION

The method of vehicle detection and counting from a video or camera sensor has been implemented and presented in the discussion. The system is implemented using BeagleBoard™ and AVR microcontroller. PCA method and its training used in this approach has 96.55% of accuracy in normal traffic condition. The accuracy of vehicle detection depends on the weather conditions and camera viewpoints. System accuracy is possible to be improved by further training or other modification on the algorithm.

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