Design and Implementation of Digital Image Processing using STM32F407ZG Microcontroller for Traffic Light Management System

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***Abstract*—Traffic jam is one of the big problems happened in a big city, such as Jakarta and Bandung. Sometimes the traffic jam is caused by the inappropriate traffic light time control. This paper describes the prototype implementation of traffic light control system by analyzing the image condition of the street captured by camera. The digital signal processing algorithm and the time of the traffic light are controlled by a STM32F407ZG Microcontroller. The size of Random Access Memory (RAM) is limited, so an additional external RAM is used in this research. The system input is 120 x 160 pixels of road image which already stored in the SD Card. A digital signal processing is used to determine which road has more traffic, and then the system will adjust the time of the traffic light based on the calculation.**

Keywords—Microcontroller, STM32F407ZG, digital signal processing, External RAM

I. INTRODUCTION

Traffic jam is a serious problem in big city such as Jakarta and Bandung. Sometimes it is happened because of the inappropriate traffic light time setting. In Indonesia, usually the time setting is done manually by referring the statistic result. With this method, it is often happened that the traffic light time is not matched with the number of the vehicle in the road especially the green light sign.

The solution of this problem is by creating a system which can determine the congestion at the road segment and use them as a parameter to control the the traffic light time.

We made a prototype of this traffic light controlling system to test the algorithm in STM32F407ZG microcontroller. This prototype can't be implemented in the real time system yet. Actually using this kind of cheap microcontroller is not recommended, we use this microcontroller because of the lack of funding.

The model system used in this research is one crossroad and the image used in this system is taken in Medan Merdeka street, Bandung. This image is used as input system of crossroad model system. The size of images are 160x120 and will be stored in SD Card. The image is taken during the day.

. The controller for image processing and traffic light management is microcontroller STM32F407ZG. Microcontroller will read the road image which already stored in SD Card. The next step, microcontroller will process the image with the process, such as edge detection, morphological operation, and labelling. After that, the result of image processing will be classified how many vehicle in the road based on height and width of segment. and give the time for green light sign.

II. BASIC THEORY

A. *Prewitt Edge Detection*

The Prewitt Edge filter is used to detect edges based on applying a horizontal and verticle filter in sequence. Both filters are applied to the image and summed to form the final result. The two filters are basic convolution filters of the form:

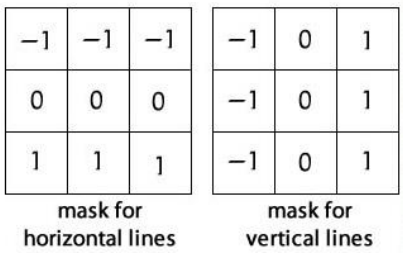


Figure 1 Prewitt Mask

Mathematically, the operator uses two 3×3 kernels which are convolved with the original image to calculate approximations of the derivatives one for horizontal changes, and one for vertical. If A is defined as the source image, and G_x and G_y are two images which at each point contain the horizontal and vertical derivative approximations. The x-coordinate is defined here as increasing in the “right”-direction and the y-coordinate is defined as increasing in the “down”-directions. At each point in the image, the resulting gradient approximations can be combined to give the gradient magnitude, using:

$$G = \sqrt{G_X{}^2 + G_Y{}^2} \quad (1)$$

The gradient magnitude can be calculated by:

$$|G| = |G_X| + |G_Y| \quad (2)$$

B. *Morphological Operation*

Morphological operation is a collection of non-linier operations related to the shape of morphology of features in an image. Morphological operations can also be applied to grayscale images. Types of morphological operations are: erosion, dilation, opening, closing, thinning and thickness.

In this research, morphological operations used are dilation and opening. Opening is used to remove the pixel which connected each other under certain threshold.

Dilation has the opposite effect to erosion. It adds a layer of pixels to both the inner and inner boundaries of regions.

C. *STM32F407ZG Microcontroller*

The STM32F407ZG is a family of microcontroller STM32F407xx. It is based on the high-performance ARM Cortex-M4 32 bits RISC core operating at a frequency of up to 168 MHz. The Cortex-M4 core features a floating point unit single precision which supports all ARM single-precision data processing instructions and data types. The STM32F407xx and STM32F407xx family incorporates high-speed embedded memories (Flash memory up to 1 Mbyte, up to 192 Kbytes of SRAM), up to 4 Kbytes of backup SRAM, and an extensive range of enhanced I/Os and peripherals connected to two APB buses, three AHB buses and a 32-bit multi-AHB bus matrix.

III. SYSTEM DESIGN

A. *General System*

Generally, the system model is described by this picture:

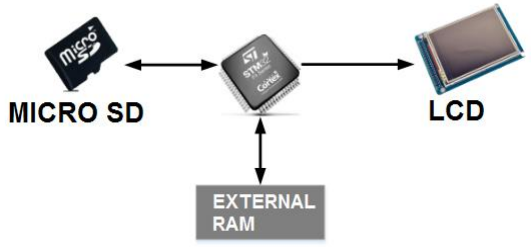


Figure 2 General System

- STM32F407ZG Microcontroller

A 32 bit microcontroller is used as the control center for the digital image processing and controlling the traffic lights

- External RAM

Random Access Memory is used because the limitation of STM32F407ZG memory to process the digital image. The capacity used is 1 MB.

- SD Card

SD Card is used as a storage media, the data saved in the SD Card is road images in grayscale.

B. *Digital Image Processing System Design*

The system input is a 160x120 pixels grayscale image which already stored in the SD Card. An edge detection using prewitt algorithm is done, then a specific mask is calculated to remove the area which is not the street. Mathematic Morphological Opening and Dilation are done to make sure the image is ready for classification. The detail is described in figure 3.

1. Grayscale image

This is the input of the system, a grayscale image stored in the SDCard. The size used is 160x120 pixels. It uses the small size because of the limited specification of the microcontroller. The images are taken from above the road.

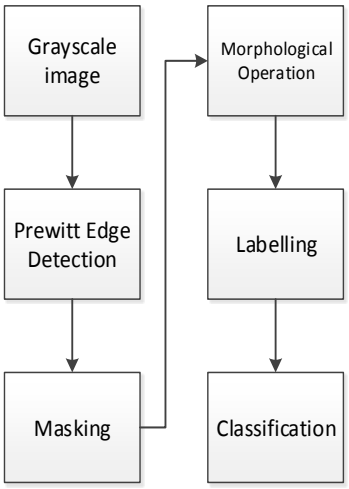


Figure 3 Image Processing Flowchart

Figure 4 Grayscale Image

2. Prewitt Edge Detection

The edge detection using Prewitt is done to detect which object in the images are vehicle or not by focusing on the intensity differences of the gray level.

3. Masking

Masking in this system is used to remove area of sidewalk. To remove the region , there are two equations used :

$$j < (-0.61 \times i) + 62.61 \quad (3)$$

and

$$j > (0.5858 \times i) + 101.4141 \quad (4)$$

Where j represents column and i represents row.

4. Morphological Operation.

In this system, morphological operation used is area open and dilation. Area open is used to remove the segment which area is less than threshold, while the threshold used in this system is three.

Dilation is morphological operations which add pixels in the edge of the object. This can connect the disconnected pixels because of the limitation of the Prewitt edge detection.

Structuring element used for the dilation process is a line with 0^0 and 90^0. The dilation value for 90^0 is 5 and 3 for 0^0. In figure 5 is shown the structure element used in this system.

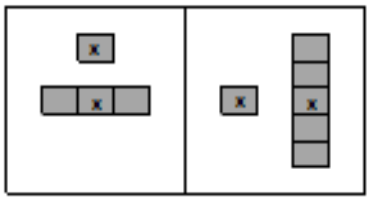


Figure 5 structuring element

a. Labelling

Labelling is the process of giving the same value in a set of connected pixels. There are two kinds of connected pixels, four connected and eight connected. In figure 5 shown the types of connected pixels.

	1	
1	X	1
	1	

(a)

1	1	1
1	x	1
1	1	1

(b)

Figure 6 Types of connected pixel (a) four connected, (b) eight connected

In this system, the connected pixels used is eight connected, and labelling is used to distinguish which is the vehicle segment.

b. Classification

Classification in this system is seeing a segment that has been labeled. If the width of the segment is less than fifteen, the segment is motorcycle. And vice versa, if more than fifteen, the segment is a car. Segment that will be examined is the segment with the row image more than forty. It is because the object with row image less than forty is irrelevant to observe.

C. Traffic Light Management

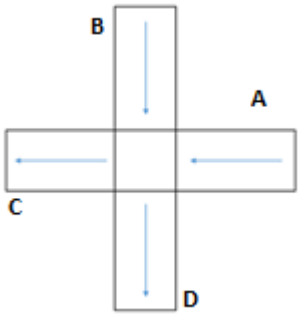


Figure 7 Cross Road Model System

Figure 7 shows the crossroad model system used in this system. The picture explains that there are two traffic flows, A-C and B-D. Therefore, this crossroad only requires two images road from the road segment A and B.

Traffic light settings are performed sequentially. When the traffic light is green in the road A, then in the road B the traffic light is red. In this system a long time setting the green sign was obtained by digital image processing result of these roads. Table 1 is a schematic arrangement of traffic light that area used in this system.

Table 1 Scheme Traffic Light Management

condition		Time (s)	
Road A	Road B	Road A	Road B
empty	empty	5	5
empty	medium	5	40
empty	full	5	60
medium	empty	40	5
medium	medium	40	40
medium	full	40	60
full	empty	60	5
full	medium	60	40
full	full	60	60

Table 2 Scheme Traffic Light Management

condition	description
empty	the maximum of vehicle in the road is 2
medium	at least in the road there are 3 car or 5 motorcycle
full	at least in the road there are 5 car or 7 motorcycle

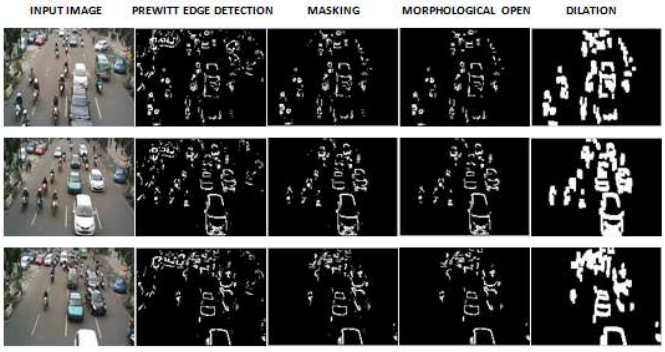
The description of empty, medium, and full are shown in table 2.

IV. TESTING AND ANALYSIS

A. *Digital Image Processing*

The digital image processing system result can be seen in the table 2. In the picture there are five columns that describe how each progress is carried out. The first column is the input of this system. The second column describes how edge detection is performed, on the edge of the object is formed which is represented by white pixels. The third column describes masking, where this process is to eliminate areas identified as sidewalk. The fourth column is area open, where this process eliminates the small noise, and the last coloumn is dilation that enhances the edges of objects are formed.

Table 1 Digital Image Processing Result



B. RAM Usage

Table 3 RAM Usage

No	External		Internal	
	Capacity	function(byte)	Capacity	function(byte)
1	76800	Image Grayscale	38400	data buffer
2	76800	Prewitt Result	2	pointer file
3	76800	Erosion Result	8	operation result
4	153600	Dilation Result	2	buffer read file
5	76800	Labelling result	20	iteration
6			16	convolution buffer
7			12	x convolution result
8			12	yconvolution result
9			4	convolution result
10			2	count element structure
11			6	operation variable
12			30	LCD Operation
13			20	Clasification operation
			76800	image processing buffer
Sum	460800		115334	

In this system the capacity of internal RAM in STM32F407ZG is 192 Kbyte, so it is not enough for this system because the minimum capacity RAM requirements of this system is 576,134 Kbytes. Therefore, the use of external RAM in this system is according to minimum requirement system.

C. Time Operating System

Table 4 Time Operating System

Process	Average Time (s)
acquisition	0.59
prewitt & mask	0.23
Erosion	0.12
Horizontal Dilation	0.14
Vertical Dilation	0.15
labellig	0.23
Total	1.46

In the Table 4, it shows the average of image processing for one image with size 160x120 is 1,46 second. It means that time would be a delay for next condition.

V. CONCLUTIONS AND SUGGESTIONS

A. *Conclutions*

STM32F407ZG microcontroller is capable to process digital image for traffic management system. The processing time is enough for a microcontroller, 1.46 seconds for each image.

Table 5 Vehicle counting result

Input Image	Real Condition		Output Image	Result	
	Car	motor		Car	motor
	1	5		0	8
	3	9		2	11
	1	1		0	1
	5	6		4	8

The accuracy for the classification result is 70% from 50 images stored in the SD Card. This accuracy is obtained by using classification from width and height of labelling segment.

Different equation of straight line is needed for different road depending on how the camera is placed.

B. *Suggestion*

- For real application on the field, use one microcontroller for one road segment integrated with camera module.

- A reliable microprocessor is needed to be use in a traffic light management system.
- To improve the image quality, an infra-red camera must be used.

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