Intelligent Rain Sensing and Fuzzy Wiper Control Algorithm for Vision-based Smart Windshield Wiper System

Kyung Chang Lee*, Man Ho Kim*, and Suk Lee*

* School of Mechanical Engineering, Pusan National University, Pusan, Korea
(Tel : +82-51-510-2320; E-mail: gclee@pnu.edu, kmh@pnu.edu, slee@pnu.edu)

Abstract: A windshield wiper system plays a key part in assuring the driver’s safety during the rainfall. However, because the quantity of rain and snow vary irregularly according to time and the velocity of the automobile, a driver changes wiper speed and interval from time to time to secure enough visual field in the traditional windshield wiper system. Because a manual operation of windshield wiper distracts driver's sensitivity and causes inadvertent driving, this is becoming a direct cause of traffic accidents. Therefore, this paper presents the basic architecture of a vision-based smart windshield wiper system and a rain sensing algorithm that regulates speed and interval of the windshield wiper automatically according to the quantity of rain or snow. This paper also introduces a fuzzy wiper control algorithm based on human’s expertise, and evaluates the performance of the suggested algorithm in an experimental simulator.

Keywords: smart wiper system, intelligent vehicle, rain sensing, wiper control, vision sensor, fuzzy control

1. INTRODUCTION

Recently, intelligent vehicles have become the center of interest in automobile, truck, industrial vehicle, and military vehicle research fields. Intelligent vehicle systems offer the potential to significantly enhance safety and convenience for both drivers and passengers. As one component of the intelligent transportation systems (ITS), the intelligent vehicle system uses intelligent sensing and control algorithms to assess the vehicle’s environment and assist the driver with safe driving. These algorithms include a driver assistance system that partially controls the vehicle for the driver’s convenience, and a collision warning system that provides emergency information to allow the driver to avoid a collision. Because of their ability to enhance the safety and convenience of drivers, intelligent vehicle systems will likely become a necessary component in an intelligent transportation system [1][2].

Among vehicle parts that have an influence on driver's safety and convenience, the windshield is an important part that much affects driver’s visual field and his safety. That is, when it is raining or snowing, a windshield wiper system plays an important role in securing his safety. However, because the quantity of rain and snow changes irregularly according to the velocity of the vehicle and the passage of time, the wiper’s speed and operation interval must be regulated frequently in a conventional wiper system. Because this control action disperses driver’s watchfulness and causes careless driving, it becomes an immediate cause of traffic accidents.

For driver’s safety and convenience, the intelligent smart wiper system has been developed for regulating the wiper’s speed and operation interval automatically according to the quantity of rain or snow [3][4]. Especially, for the smart wiper system to act normally, the rainfall state, such as the quantity and speed of rain that changes according to the velocity of the vehicle and the passage of time, should be measured exactly. In the large majority of the intelligent smart wiper systems, an optical lane sensor is used for satisfying this purpose [3]. To measure the quantity of rain, the optical lane sensor is based on the feature that the light’s refraction is different according to a medium. That is, because the reflection angle varies according to the wetness of the windshield, the detected quantity of light in the wet windshield is different from that in the dry windshield. Based on these principles, the infrared LED (light-emitting diode) sensor emits lights to the windshield in a smart wiper system, and then the photo diode sensor measures the quantity of light that is reflected by raindrop on the windshield surface. As a result, the quantity of rain can be calculated from the quantity of light measured. However, the optical lane sensor has not a very high accuracy because of the shortcomings such as the interference between a LED and an external light source.

Therefore, a filter adhered to the windshield surface is used for removing the interference of the external light source. That is, the filter reflects the LED light in the inner side of the vehicle and shines directly toward the vision sensor, but rejects the external light on the outer side of the vehicle. But, because the windshield with the filter bracket has to be used for preventing transmission of light, it faces a cost problem that it would be more expensive than the conventional windshield. Besides, the optical rain sensor can calculate the rain level in terms of quantity of rain per unit time, as well as the rain intensity represented by the frequency of raindrops adhered to a relatively small sensing area of windshield. Therefore, precise measurement is difficult due to the incomplete information recognized from narrow area of the windshield when raindrops adhere to only partial area of the windshield or rain trickles down the windshield.

For solving these problems, this paper presents a concept of vision-based smart wiper system that can measure a relatively wider windshield area than the conventional system. Especially, the vision sensor has advantage that can measure not only the rain level but also the rain distribution because of its wider sensing range than the optical sensor. Here, the rain distribution is defined as dispersion level of raindrops on the sensing area of the windshield. This method may grasp the rainfall state more exactly when disturbance occurs.

In this paper, we present the basic structure of a vision-based smart wiper system and rain sensing algorithm. An effective algorithm is specially developed that can recognize the rainfall state during the daytime and the nighttime separately. Also, this paper introduces an intelligent wiper control algorithm is based on fuzzy control that can regulate the wiper speed and wiper interval effectively. Finally, this paper implements an experimental simulator in the laboratory, and evaluates the performance of the proposed algorithm in the simulated rainfall state.

This paper consists of six sections including this introduction. Section 2 introduces the basic structure of a vision-based smart wiper system, and Section 3 presents the rain sensing algorithm. The intelligent wiper control system using fuzzy control is described in Section 4, and the experimental simulator is implemented and the proposed algorithm is evaluated in Section 5. Finally, a summary of the work and conclusions are presented in Section 6.

2. STRUCTURE OF VISION-BASED SMART WIPER SYSTEM

In general, the optical rain sensor is used for measuring the rainfall state in a conventional smart wiper system. But, because its sensing method is faced with several problems, which make it difficult to measure the rain level and rain intensity from a relatively narrow area less than 1cm of width, it is difficult to grasp the exact rainfall state that changes irregularly by local disturbance.

Therefore, to solve these problems, we developed an intelligent smart wiper system using a vision sensor as shown in Fig. 1. The smart wiper system consists of a wiper motor, a wiper switch, a fuzzy controller, a vision sensor, and a LED. Here, the wiper switch is used for activating the smart wiper system. And, the fuzzy controller includes the rain sensing algorithm that calculates the rain level and rain distribution from a rain image captured by the rain sensor. Also included in the fuzzy controller is the fuzzy control algorithm that processes the wiper speed and wiper interval from inferred results such as the rain level and rain distribution. Finally, the vision sensor is installed in the ceiling region of the vehicle for recognizing the windshield area, and the LED is installed on the top region of the dashboard close to the windshield in order to emit light to the sensing area on the windshield.

To guarantee the performance of the vision-based smart wiper system, an external background outside of the vehicle must be ignored, and only the raindrops on the windshield can be extracted from an image captured by the vision sensor. For this purpose, we have focused the vision sensor on the raindrops for requiring a desirable image and have chosen the Low DOF (depth of field) for embossing the focused raindrops. As a result, the external background outside of the windshield is vague and only the focused raindrops become distinct.

Additionally, we use the high intensity LED light to capture a necessary region exactly from the target object. Also, to receive the high intensity LED light reflected by the raindrop on the windshield, the vision sensor and LED are installed at θ angle to the windshield.

Finally, the vision sensor can be affected by an external light source of the vehicle such as sunlight in the daytime, road lights of signal lamps and street lamps, headlights of cars in the reverse lane, and stoplights of the cars in front in the nighttime. Part of disturbances such as sunlight or road light can be filtered by means of equipping the windshield with a vision sensor at an angle of θ as shown in Fig. 1. But, effects of the external light source such as stoplights or headlights cannot be eliminated. Therefore, an appropriate image processing algorithm is necessary to solve the effect of these external light sources. For this purpose, we develop an image processing algorithm separately for the daytime and nighttime.

3. RAIN SENSING ALGORITHM OF SMART WIPER SYSTEM

Fig. 2 shows the rain sensing algorithm for vision-based smart wiper system. Two algorithms for the daytime and nighttime are specially developed for the sensors to distinguish the rainfall state effectively in the nighttime. In the figure, after a wiper switch is turned on, a vision sensor acquires an image of raindrops on the windshield. And then, a driving time zone is decided by means of checking the state of the taillight. That is, if the taillight is turned on, we assume that a car may be driving in the nighttime. Next, the image processing algorithm for the daytime or nighttime is executed for recognizing the captured image, and then the rain level and distribution is computed. Finally, the intelligent fuzzy wiper control algorithm is executed, and the wiper speed and interval are regulated on the basis of the calculated fuzzy output.

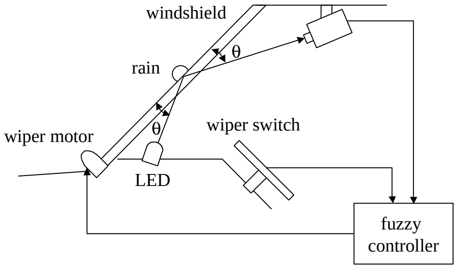


Fig. 1. Schematic diagram of vision-based smart wiper system.

3.1 Daytime image processing algorithm

Because the raindrops on the windshield do not have immovable shape, it is not easy to recognize the exact image of the raindrops from the windshield. But, if the boundary of the raindrops can be recognized effectively, the approximate size and distribution of raindrops can be calculated.

In this work, the boundary of raindrops is detected by the Sobel mask [5], of which processing speed is very fast. Fig. 3(a) shows an original image of raindrops that is filmed in the experimental simulator explained in Section 5. And, Fig 3(b) shows a result processed by the Sobel mask. In the figure, we can verify that the boundary of raindrops is comparatively soft and clear as the result of processing of the Sobel mask.

H o w e v e r , the boundary of raindrops processed by the Sobel mask includes the dim elements of the background outside of the windshield. Th at is, the boundary of the background is very dim as shown in Fig. 3(b), because the background outside the windshield was out of f ocus by means of Low DOF method. For removing dim boundary of background in this work, the single threshold T is applied as sh own in Equ. 1 [6]. In this equation, T value is selected as 125.

$$F(x,y) = \begin{cases} high(255) & if \;\; f(x,y) \geq T \\ low(0) & otherwise \end{cases} \tag{1}$$

Fig. 3(c) shows an image after the binary image processing algorithm with the single threshold. In this figure, we can verify that the dim boundary of the background is removed perfectly because it has low gray value.

Next, we apply the dilation operation to emboss the raindrops more and more [5]. In general, because the dilation operation can extend the outermost pixels of the boundary, the focused raindrop s are enlarged, and the background is reduced after the dilation op eration. In this work, the 3×3 dilation mask, whose value of all pix els is 0, is used for faster computational speed [7]. Fig. 3(d) shows a final image after the dilation operation. Comparing Fig. 3(c) wi th Fig. 3(d), we can verify that the boundary of raindrops is embos

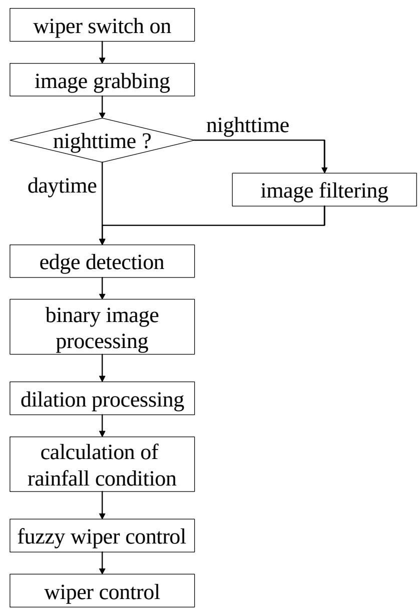


Fig. 2. Flowchart of rain sensing algorithm..

sed distinctly by the dilation operation.

3.2 Nighttime image processing algorithm

Disturbances due to the external light source such as sunlight in the daytime, road lights of signal lamps and street lamps in the nighttime, can be removed by adjusting the position angle of the vision sensor as shown in Fig. 1. However, the external light source, such as the headlights of cars in the reverse lane and stoplights of the cars in front in the daytime, is not eliminated effectively. Hence, the image processing algorithm should be modified so that the external light source is removed.

For this purpose, we chose the diffusion of light in this work. In general, high frequency elements of an image have a relatively sharp characteristic feature, but low frequency elements have a rather cloudy characteristic feature. That is, the internal LED light source reflected directly by raindrops is distinct and has high frequency elements, but the external light source processed by the Low DOF is blurred and has low frequency elements. Therefore, disturbances by the external light source can be removed by eliminating low frequency elements from the image.

For removing low frequency elements, we chose the n^{th} order Butterworth high pass filter that has the cutoff frequency locus as follows;

$$H(u,v) = \frac{1}{1+[D_0 / D(u,v)]^{2n}} \quad (2)$$

where D(u,v)is distance from the origin to (u,v) on the frequency plane. Also, the cutoff frequency D_0 is selected to 32, and n is selected to 16 in this paper.

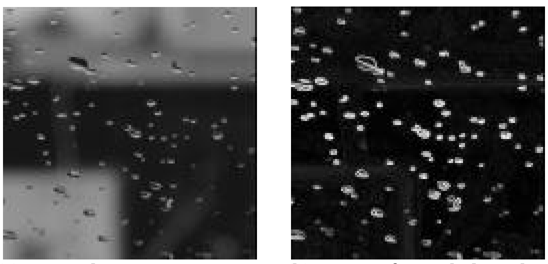
Fig. 4 shows a result after applying the high pass filter to a nighttime image with stoplight acquired in the experimental simulator. If the boundary of the stoplight is not eliminated but recognized, the original image (Fig. 4(a)) will be considered that it has very many raindrops. However, after the high pass filter is applied to the original image and low frequency elements are removed, we can acquire an image (Fig. 4(b)) showing that the stoplight is eliminated perfectly.

3.3 Rainfall state decision algorithm

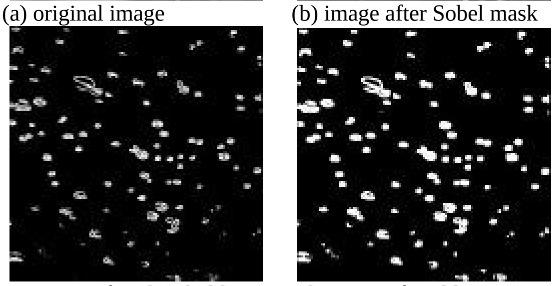
For controlling of the wiper in the smart wiper system, the rainfall state should be decided. In this work, we use the rain level and rain distribution to decide the rainfall state. The rain level is defined as the number of raindrop pixels (its value is high) in a processed image (256×256 pixel). Also, the rain distribution is computed following these procedures; 1) Divide overall area of 256×256 pixel image into 16×16 pixel unit area. 2) If one more than pixel in the 16×16 pixel unit area is high value (that is, one more than pixel with raindrop exists in unit area, assign high to all pixel of 16×16 unit area. 3) And then, the rain distribution is defined as the ratio of the number of recalculated pixels with high value to the number of overall pixels (65,536).

Fig. 5 shows an example how the rain level and rain distribution are calculated. Fig. 5(a) shows an image of drizzling rain. In this figure, one pixel per eight pixels is high value. Because all pixels of 16×16 pixel unit area should be assigned high value if one more than pixel is high, we can assign high value to all pixels of 256×256 pixel image. Fig. 5(b) shows an image when a relatively thick rain drops to the narrow area of the windshield sometimes or raindrops adhere to a small area of the windshield by various distributions. In this figure, central 4 unit area is high value in 256×256 pixel image, and the other unit area is low value.

As a result, the rain level of Fig. 5(a) and Fig. 5(b) are 1024 pixels equally. However, the rain distribution of Fig. 5(a) is 100% (256/256×100), which means that it is drizzling. And, the rain distribution of Fig. 5(b) is 1.56% (4/256×100), which means that raindrop adhere to the windshield sparsely. The wiper control algorithm is designed on the basis of this line of reasoning, and we can see that the wiper runs frequently in the Fig. 5(a) and one time in the Fig. 5(b). These examples verify that it is possible to recognize the rainfall state by using rain level and rain distribution

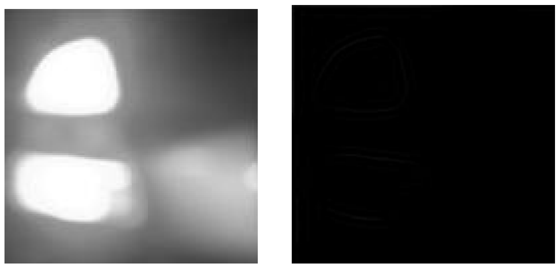


(a) original image (b) image after Sobel mask



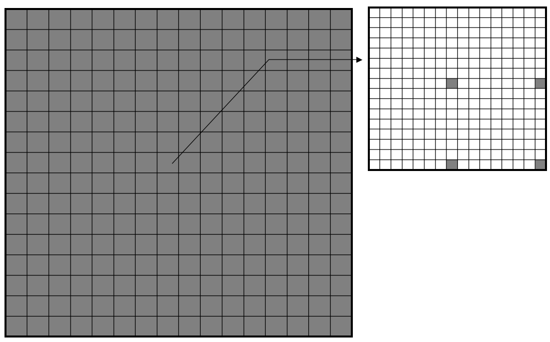
(c) image after threshold (d) image after dilation

Fig. 3. Result of image processing of the daytime.

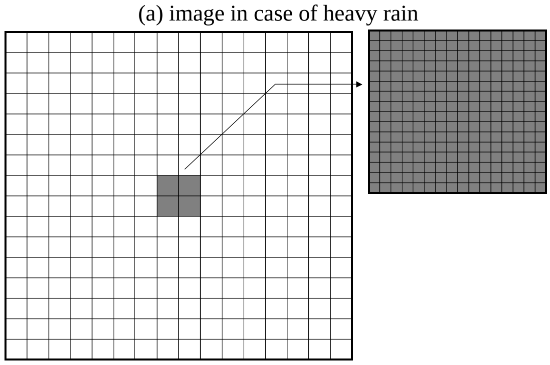


(a) original image (b) image after high pass filtering

Fig. 4. Result of high pass filtering of the nighttime image.



(a) image in case of heavy rain



(b) image in case of light rain

Fig. 5. Example of rainfall condition by wetness and distribution.

in a way that resembles the human sight.

4. FUZZY WIPER CONTROL ALGORITHM

In this paper, a fuzzy control algorithm is used to regulate the wiper speed and wiper interval using the calculated rain state, that is, the rain level and rain distribution after the image processing. Especially, because the decision-making ability of human drivers is not designed to mathematical model exactly, the wiper control using the fuzzy logic algorithm must be a very efficient method [8][9].

Fig. 6 shows the structure of the fuzzy wiper control algorithm of the smart wiper system. In the figure, the fuzzy controller consists of three parts; (1) the fuzzifier that converts the rain level and rain distribution after image processing from the original image captured by the vision sensor into linguistic values, (2) the inference engine that creates the fuzzy output using fuzzy control rules generated from expert experiences, and (3) the defuzzifier that calculates the wiper speed and wiper interval from the inferred results.

To acquire the fuzzy control rules, we use the wiper contr ol operation by the human driver as shown in Table 1 [3]. That is, if it is drizzling lightly or raindrops adhere to the local area of the windshield, the wiper should be set to low speed and long interval. But, if it is raining heavily or raindrops adhere to the overall area of the windshield, the wiper should be set to high speed with no interval. From 100 experimental images captured in the experimental simulator, we acquired the fuzzy control rules as shown in Table 2.

Fig. 7 shows the membership function of the fuzzy input and output linguistic variables. The linguistic variables of the rain level are defined as Dry, Drizzle, and Wet, and those of the rain distribution are defined as Light, Medium, and Heavy as shown in Fig. 7(a). Here, we selected that the linguistic value of the rain distribution in the daytime is equal to that in the nighttime. But, the linguistic value of the rain level in the nighttime is smaller than that in the daytime, because all the boundary of raindrops are detected in the daytime, but the boundary of the light source reflected by raindrops are detected in the nighttime.

And then, the linguistic variables of the wiper speed are defined as Zero, Low, and High as shown in Fig. 7(b). Here, the wiper speed depends on the performance of the wiper motor. In this paper, we defined that the wiper stops if the linguistic value is lower than 1, the motor activates at low speed if the linguistic value is 5, and the motor activates at high speed if the linguistic value is larger than 9. Finally, the linguistic variables of the wiper interval are defined as Zero, Short, and Long as shown in Fig. 7(b). Here, we defined that the wiper interval varies from 0 msec to 3,000 msec.

For faster execution of the fuzzy logic controller, the Mamdani's min-max inference method is used. Also, the MoM (Mean-of-Maximum) method is used for defuzzification of the wiper speed, and the CoA (Center-of-Area) method is used for defuzzification of the wiper interval. [10][11]

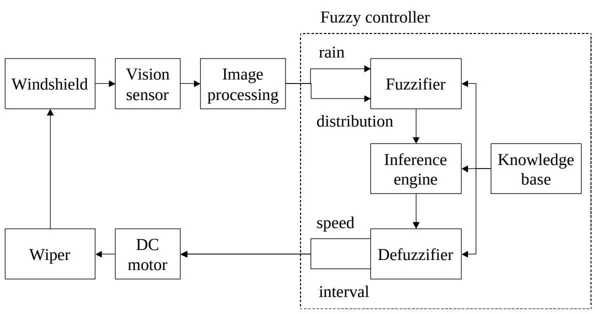


Fig. 6. Schematic diagram of fuzzy controller.

Table 1. General linguistic rules for controlling a wiper.

Antecedent	Consequence
IF it is not raining or drizzling	THEN the wiper should be set to "Off."
IF it is drizzling lightly	THEN use a long delay interval setting on the wiper.
IF it is drizzling heavily	THEN use a short delay interval setting on the wiper.
IF it is raining lightly	THEN use the continuous low speed setting on the wiper.
IF it is raining heavily	THEN use the continuous high speed setting on the wiper

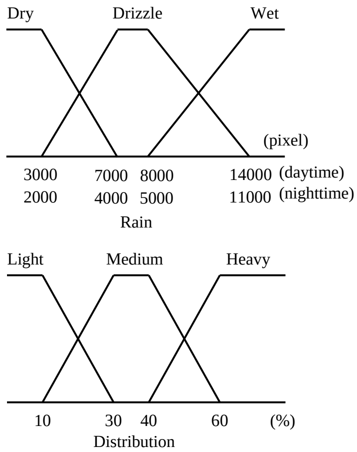
Table 2. Fuzzy control rules for controlling a wiper.

(a) Speed

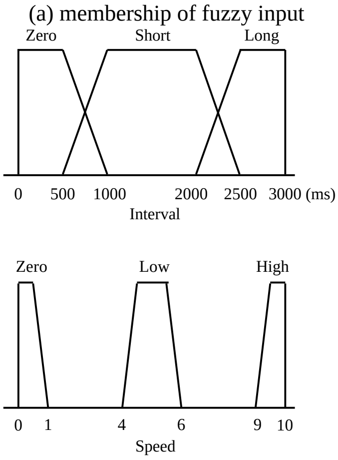
Distribution \ Rain	Dry	Drizzle	Wet
Light	Zero	Low	Low
Medium	Low	Low	Low
Heavy	Low	Low	High

(b) Interval

Distribution \ Rain	Dry	Drizzle	Wet
Light	Long	Long	Short
Medium	Long	Short	Zero
Heavy	Short	Zero	Zero



(a) membership of fuzzy input



(b) membership of fuzzy output

Fig. 7. Membership functions of fuzzy input and output variables.

5. PERFORMANCE EVALUATION OF VISION-BASED SMART WIPER SYSTEM

In this paper, an experimental simulator is implemented based on the structure as shown in Fig. 1 to evaluate the performance of the suggested rain sensing algorithm and the fuzzy wiper control algorithm of the vision-based smart wiper system. In the experimental simulator, one red high density LED with the highest strength and the longest wavelength is used. Also, a frame grabber is the Euresys's Picolo board, and a CCD camera is Pulnix's TM-200. Finally, the iris is especially fixed to F0.4 to acquire the maximal open.

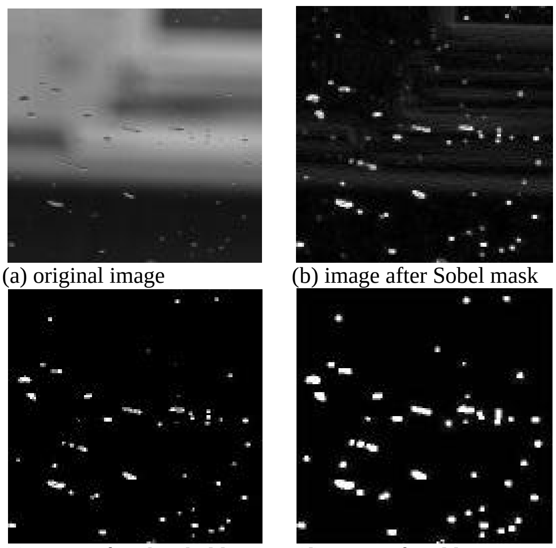
From the above experimental setup, we acquired several experimental images with 256×256 pixels from the CCD camera, and evaluated performance of the suggested rain sensing algorithm and the fuzzy wiper control algorithm.

5.1 Result of image processing in the daytime

Fig. 8 shows the results after the image processing algorithm of the daytime, when it is drizzling lightly. When the boundary of an original image as shown in Fig. 8(a) is detected by Sobel mask, we verify that the boundary of the external background is vague as shown in Fig. 8(b). And then, that is removed by applying the threshold operation as shown in Fig. 8(c). Next, when the dilation operation is applied to Fig. 8(c), we acquire the final clearer image as shown in Fig. 8(d). Finally, we verify that the rain level is 2,183 pixels and the rain distribution is 30.5% by means of the rainfall state decision algorithm. Using the above fuzzy input, we calculated that the wiper interval is 2,450msec, and that the wiper speed is a low speed mode (its value is 5) from the fuzzy wiper control algorithm. That is, if it is drizzling lightly, we verify that the wiper should be activated in low speed mode with an interval of 2.45 sec.

Fig. 9 shows the results of the experiment in a heavy rain. In the figure, the rain level is 15,831 pixels, and the rain distribution is 83.2%. From these results, we acquire that the wiper interval is 350msec and the wiper speed is high speed mode (its value is 9). That is, if it is raining heavily, we verify that the wiper should be activated in high speed mode.

From these experimental results, we can acquire the exact rainfall state from the suggested rain sensing algorithm, and determine the wiper speed and wiper interval from the suggested fuzzy wiper control algorithm.



(a) original image (b) image after Sobel mask

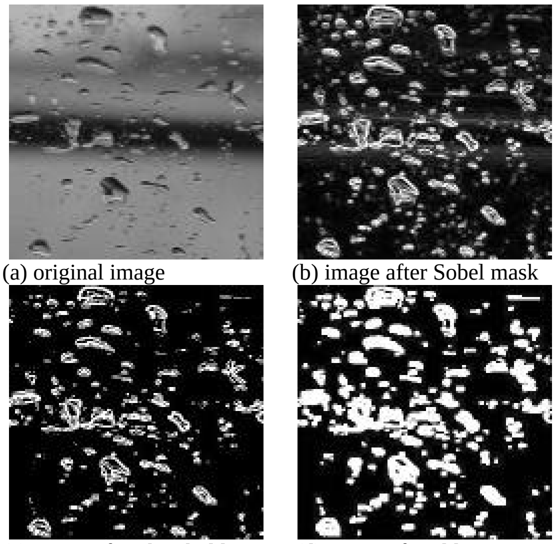
(c) image after threshold (d) image after dilation

Fig. 8. Result of image processing under drizzling condition in the daytime.

5.2 Result of image processing in the nighttime

Fig. 10 shows the results obtained after the image processing algorithm of the nighttime, when it is drizzling lightly and an external light source is not detected. After applying the Butterworth high pass filter to an original image as shown in Fig. 10(a), we acquire an image as shown in Fig. 10(b) that has low gray value of raindrops. After detecting the boundary of Fig. 10(b) using Sobel mask, we verify that the boundary of raindrops is distinct as shown in Fig. 10(c). Finally, after threshold and dilation operations (Fig. 10(d)), we acquire that the rain level is 3,352 pixels, and that the rain distribution is 44.5%. Using the above fuzzy input, we calculate that the wiper interval is 1,840msec, and that the wiper speed is low speed mode (its value is 5) from the fuzzy wiper control algorithm. That is, if it is drizzling lightly in the nighttime, we verify that the wiper should be activated in low speed mode with an interval of 1.84 sec, which is faster than the wiper interval during the daytime.

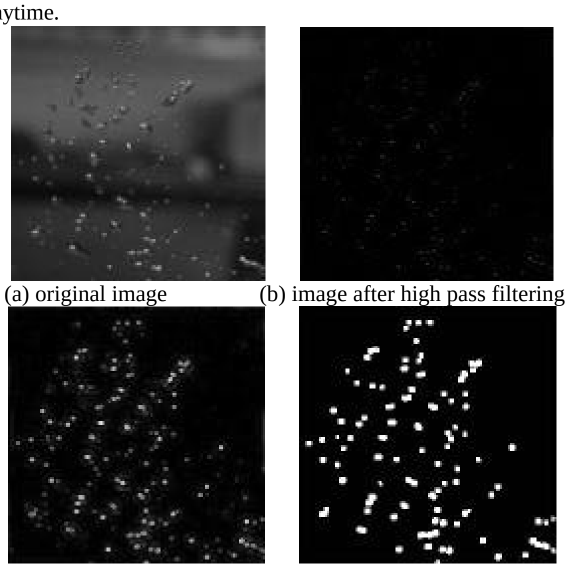
Fig. 11 shows the results of the experiment conducted when it is raining heavily and an external light source such as stoplight of the front cars is detected. In the experimental simulator, the



(a) original image (b) image after Sobel mask

(c) image after threshold (d) image after dilation

Fig. 9. Result of image processing in wet condition in the daytime.



(a) original image (b) image after high pass filtering

(c) image after Sobel mask (d) image after threshold and dilation

Fig. 10. Result of image processing under drizzling condition in the nighttime.

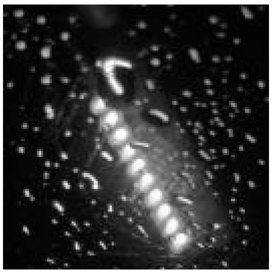
external light source is implemented by setting LEDs outside of the simulator. That is, the bright part of an original image as shown in Fig. 11(a) is attributed to LED light source to be set up outside of windshield. After applying the Butterworth high pass filter (Fig. 11(b)) and the Sobel mask (Fig. 11(c)) to the original image, we verify that the boundary of raindrops is clear, and that the external light source does not appear. After the threshold and dilation operations (Fig 11(d)), we acquire that the rain level is 8,449 pixels and the rain distribution is 73.0%. From the fuzzy wiper control algorithm, we calculate that the wiper interval is 350msec and the wiper speed is high speed mode (its value is 9). That is, if it is raining heavily in the nighttime, we verify that the wiper should be activated in a high speed mode the same way as in the daytime.

From these experimental results, it was verified that the suggested algorithm is efficient in determining the wiper speed and wiper interval during the nighttime, when there is an external light source such as headlights or stoplights.

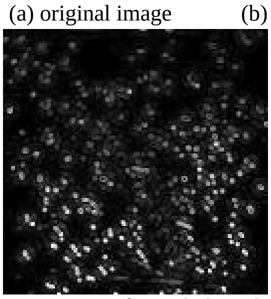
6. SUMMARY AND CONCLUSIONS

In this paper, we presented the structure of a vision-based smart wiper system to improve the safety and convenience of drivers, and introduced a rain sensing algorithm to recognize the rainfall state using the rain level and rain distribution. Also, we introduced a fuzzy wiper control algorithm to determine the wiper speed and interval from the calculated rain level and rain distribution. Especially, a rain sensing algorithm is developed that can calculate necessary information for the appropriate wiper control in the environment with an external light source such as sunlight in the daytime, road lights, headlights, and stoplights in the nighttime. Finally, an experimental simulator is implemented, and the performance of the suggested algorithms is evaluated through a series of experiments. The conclusions derived from the research are as follows:

- Because a vision sensor has a capability similar to human sight, we can extract raindrops from the external background using Low DOF of vision sensor in the daytime. Also, we verify that the rainfall state recognized by means of the suggested rain sensing algorithm is similar to that observed by human sight, and the wiper control information acquired by means of the suggested fuzzy wiper control algorithm is similar to that decided by the human driver.


(a) original image


(b) image after high pass filtering


(c) image after Sobel mask

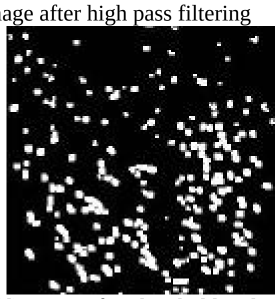

(d) image after threshold and dilation

Fig. 11. Result of image processing in wet condition in the nighttime.

- We verify that the rainfall state can be recognized by the suggested algorithm in the nighttime with an external light source such as sunlight in the daytime, the road light of signal lamps and street lamps, headlights of cars in the reverse lane, and stoplights of the cars in front in the nighttime.
- We verify that the suggested algorithm with the rain level and rain distribution may be effective in deciding the rainfall state to be similar to that decided by the human driver, when it is drizzling or raining or when raindrops adhere to the narrow area of the windshield.

However, this paper focuses on the performance evaluation of the suggested algorithms in the test image captured from an experimental simulator implemented in a laboratory. Therefore, the applicability of the suggested algorithm has yet to be verified outside the laboratory when it is raining. Moreover, because the rainfall state varies according to the velocity of the vehicle and the passage of time, it is necessary to develop an algorithm that also takes these conditions into consideration. Finally, a long-term field test is necessary in order to apply the suggested structure to an automotive.

REFERENCES

[1] A. Broggi, “Intelligent vehicle applications worldwide,” *IEEE Intelligent Systems*, vol. 15, no. 1, pp. 78-81, Jan. 2000.

[2] L. Figueiredo, I. Jesus, J.A.T. Machado, J.R. Rerreira, and J.L. Martines de Carvalho, “Towards the development of intelligent transportation systems,” *2001 IEEE Intelligent Transportation Systems Conference Proceedings*, pp. 1206-1211, 2001.

[3] K.C. Cheok, K. Kobayashi, S. Scaccia, and G. Scaccia, “A fuzzy logic-based smart automatic windshield wiper,” *IEEE Control Systems*, vol. 16, no. 6, pp. 28-34, Dec. 1996.

[4] H. Kato and T. Matsuki, “Raindrop sensor using electric double layers,” *Sensors and Actuators B: Chemical*, vol. 1, no. 1-6, pp. 308-311, Jan. 1990.

[5] R.C. Gonzalez and R.E. Woods, *Digital image processing*, Addison-Wesley Publishing Company, 1992.

[6] R. Crane, Simplified approach to image processing, Prentice-Hall, 1997.

[7] D.H. Jang, Implementation of digital image process using Visual C++, PC Advances, 1999.

[8] H.C Lee, M. Tomizuka, “Adaptive vehicle traction force control for intelligent vehicle highway systems (IVHSs),” *IEEE Transactions on Industrial Electronics*, vol. 50, no. 1, pp. 37-47, Feb. 2003.

[9] S.Y. Foo, “A fuzzy logic approach to fire detection in aircraft dry bays and engine compartments,” *IEEE Transactions on Industrial Electronics*, vol 47, no. 5, pp. 1161-1171, Oct. 2000.

[10] C.C. Lee, “Fuzzy Logic in Control Systems: Fuzzy Logic Controller – Part I,” *IEEE Transactions on Systems, Man, and Cybernetics*, vol. 20, no. 2, Mar.-Apr, pp. 404-418, 1990.

[11] C.C. Lee, “Fuzzy Logic in Control Systems: Fuzzy Logic Controller – Part II,” *IEEE Transactions on Systems, Man, and Cybernetics*, vol. 20, no. 2, Mar.-Apr, pp. 419-435, 1990.