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Automatic Wiper Controller Using Optical Rain Sensor

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An automatic wiper which detects raindrops with an optical rain sensor and controls the wiper interval was developed and marketed.
This automatic wiper is implemented by combining an existing wiper system with a sensor and controller. When raindrops shut off the sensing beam between the light emitting and light sensitive elements, the sensor detects a change in light intensity incident to the light sensitive element. This is how raindrops are detected. A power control circuit is incorporated so that the sensitivity of the sensor will not deteriorate when the intensity of incident light is lowered due to contamination. In addition, a failsafe feature is provided to assure wiper operation when raindrops cannot be detected because the sensing beam is shut off by snow or other matter stuck to the sensor.
The controller is a four-bit microprocessor which processes signals from the sensor and controls the wipers to a driver's liking.
The automatic wiper was tested using a rainfall simulator and in a field test. The results have shown that the automatic wiper can respond appropriately to varying driving speeds and rainfall intensities. An automatic wiper system which achieves the design goals for convenience and comfort has been developed.

1. Introduction

Windshield wipers are important because they permit driving during rainy and snowy conditions. Figure 1 shows the history of wipers. Note that the last remarkable development was that of electric wipers. Intermittent wipers which are convenient when it is drizzling or just after it has stopped raining have recently been developed. In addition, stepless intermittent wipers, the interval of which can be freely selected by the driver, and speed following wipers, the interval of which automatically changes in response to the vehicle speed, are becoming popular. In addition, some wiper systems which use rain sensors to control the interval in response to rainfall and vehicle speed variations are beginning to appear. This is because there is an increasing demand for windshield wipers using the latest in electronics technology to meet the driver's comfort.

Research and development for raindrop detection started a long time ago, but became more popular around 1970. The available detection

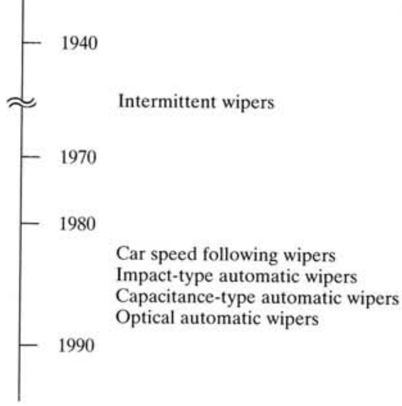


Figure 1. History of windshield wipers

methods are based on the following:

① impact energy variations, ② capacitance variations, ③ conductivity variations, and ④ light intensity variations. Methods ① and ② have already been implemented for the automobile and are rapidly spreading.

Unfortunately, these wipers have drawbacks in that they sometimes malfunction when exposed to vibration or loud noise and may fail to operate when it is drizzling or snowing. To overcome this we have developed an optical automatic wiper with its interval automatically controlled by using a rain sensor which responds to light intensity variations. This wiper is outlined below.

2. System overview

2.1 Purpose of development

In developing the automatic wiper, we intended to fulfill the following purposes:

1) Convenience: To dispense with troublesome wiper operation needed when rainfall conditions change or when driving conditions change, including the car speed and entry to or exit from tunnels.
2) Comfort: To operate the wiper with response to changing rainfall and driving conditions, thus keeping the driver's windshield clear.
3) Installation: The system is easy to install.

2.2 System configuration

Figure 2 shows the system configuration. The automatic wiper system consists of an optical rain sensor installed on the hood and a controller mounted inside. The contoller is connected to the existing wiper switch and motor. Since the automatic wiper is an extension to the existing wiper system, it is easy for the driver to control. The functions of the sensor and controller are outlined below.

1) Rain sensor (raindrop detection function)

The rain sensor detects raindrops by sensing the change in light intensity which occurs when raindrops cross the near-infrared sensing beam between the light emitting and light sensitive elements.

2) Controller

The controller has the following three functions:

① Semi-automatic function: When the wiper switch is set to the "intermittent" position, the wiper moves once, then moves at intervals automatically controlled. The interval can range from Lo (continuous) operation to 24 seconds according to a rainfall. When the wiper switch is set to Lo or Hi, the wiper operates like a conventional wiper. Figure 3 outlines the operation of the automatic wiper.

② Washer interlock function: When the washer switch is turned on, the wiper moves. When it is turned off, the wiper will stop after two wiping cycles.

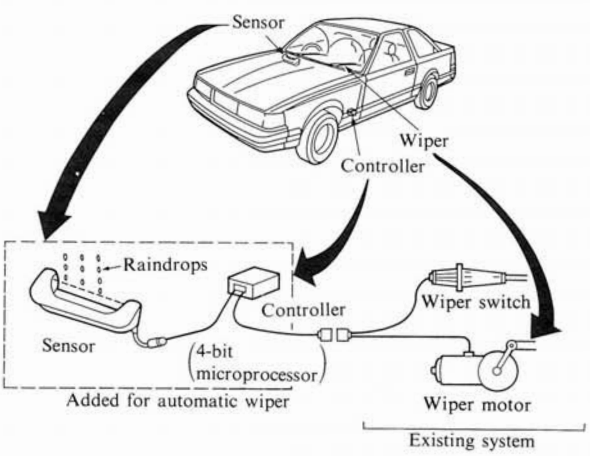


Figure 2. System configuration

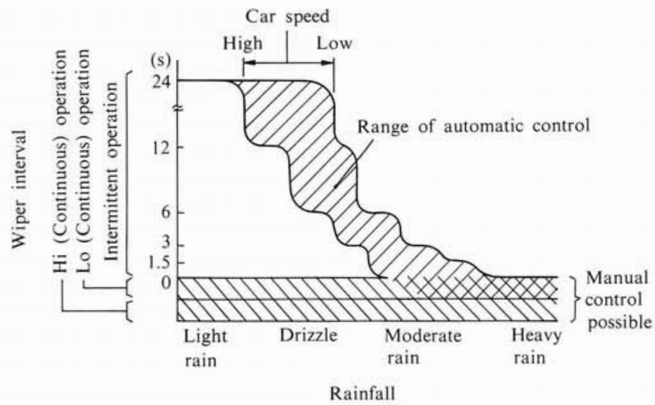


Figure 3. Operation of automatic wiper

③ Failsafe function: It is assured that the wiper operates at 6-second intervals when the raindrop detection function is disabled because the sensing beam is completely blocked by dust, snow, or other matter stuck to the sensor.

3. Sensor

3.1 Principle of raindrop detection

Raindrops stuck on a car's windshield may make round shadows in the car by blocking light from headlamps or on-coming cars. Raindrops seem to be transparent; however, they do cause diffraction of light, to appear to be somewhat opaque. That is to say, when a water drop is placed in the light, it blocks some of the light, thus making a shadow. This is called masking effect.

As shown in Figure 4, the beam from the light emitting element [near infrared emitting diode (hereafter called the LED)] is received by the light sensitive element [silicon photodiode (hereafter called the photodiode)]. When raindrops cross this beam, the intensity of the light incident to the photodiode changes according to the size and number of the raindrops. The degree of rainfall is determined by the degree and frequency of changes in the intensity of the received light.

3.2 Basic design

3.2.1 Study of raindrop size to be detected

Figure 5 shows the relationship between the degree of rainfall, raindrop diameter, and wiper interval. If the automatic wiper is intended to control the wiper interval within the range from intermittent operation to Lo (continuous) operation, the range of rainfall in which the automatic wiper can achieve the intended control is from light rain to a rainfall of 1.5 mm/h or so. Therefore, the diameters of raindrops that should be detected are from 0.3 to 2.3 mm.

3.2.2 Study of sensing beam diameter

Suppose that a part of the sensing beam with a cross sectional area of *S*p in the direction of transmission is shut off by a raindrop with a radius of *a*. The light intensity change rate $\triangle P$ caused by this is given by the following:

$$\triangle P = \pi a^2 / Sp \text{ ---------- } (1)$$

Figure 6 shows the relationship between sensing beam diameter and received light intensity change rate $\triangle P$ which is obtained by equation (1). Since the received light intensity change rate is inversely proportion to the beam diameter, smaller raindrops can be detected more easily as the beam diameter is

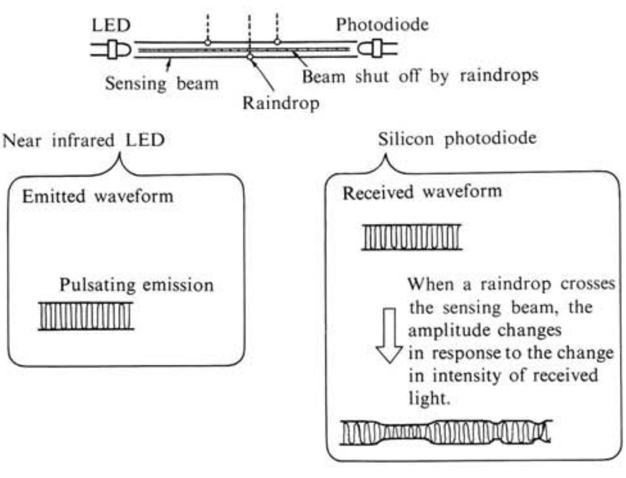


Figure 4. Principle of raindrop detection

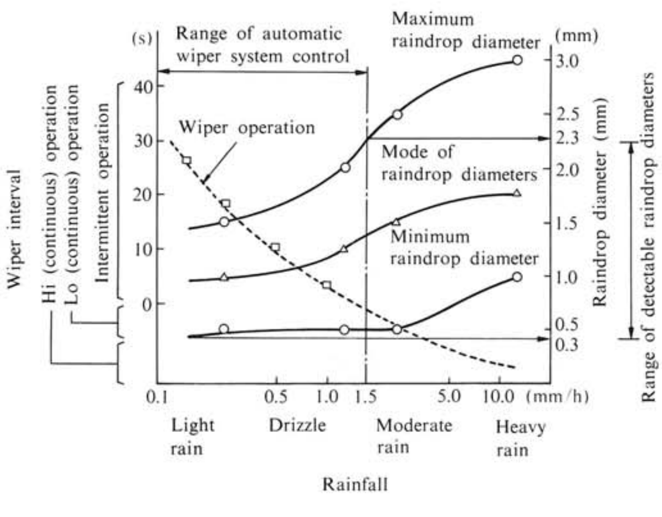


Figure 5. Relationship between rainfall, wiper operation, and raindrop size[1)]

smaller. However, before ideal wiper control can be achieved, it must be possible to determine the amount of rainfall quantitatively. Therefore, as discussed in the preceding section, the sensor must be able to detect raindrops with diameters of 0.3 to 2.3 mm without saturation. This means that the sensing beam diameter should be at least 2.3 mm because it must be equal to or greater than the saturation limit determined by the maximum detectable raindrop diameter. For simple structure and low cost, we considered determining the sensing beam only by the shape of the LED and photodiode and decided that the sensing beam diameter be 3 mm.

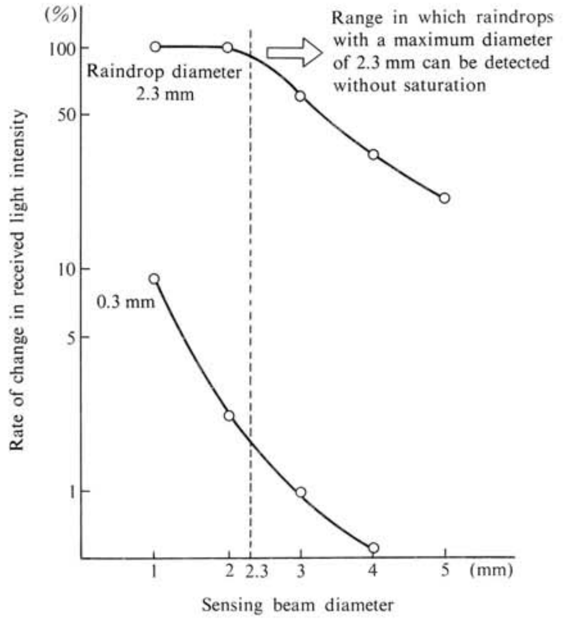


Figure 6. Relationship between sensing beam diameter and received light intensity change rate

3.3 Circuit

Figure 7 shows a block diagram of the rain sensor circuit. The circuit consists of four blocks: a light emitting block which drives the light emitting element in a pulsating way, a light receiving block which detects changes in the intensity of the light incident to the light sensitive element, a raindrop pulse processing block which converts the detected received light intensity changes to raindrop signals, and a power control block which stabilizes the intensity of the received light. The blocks are outlined below.

3.3.1 Light emitting block

The light emitting element is an LED which has a relatively strong directivity. It is driven in a

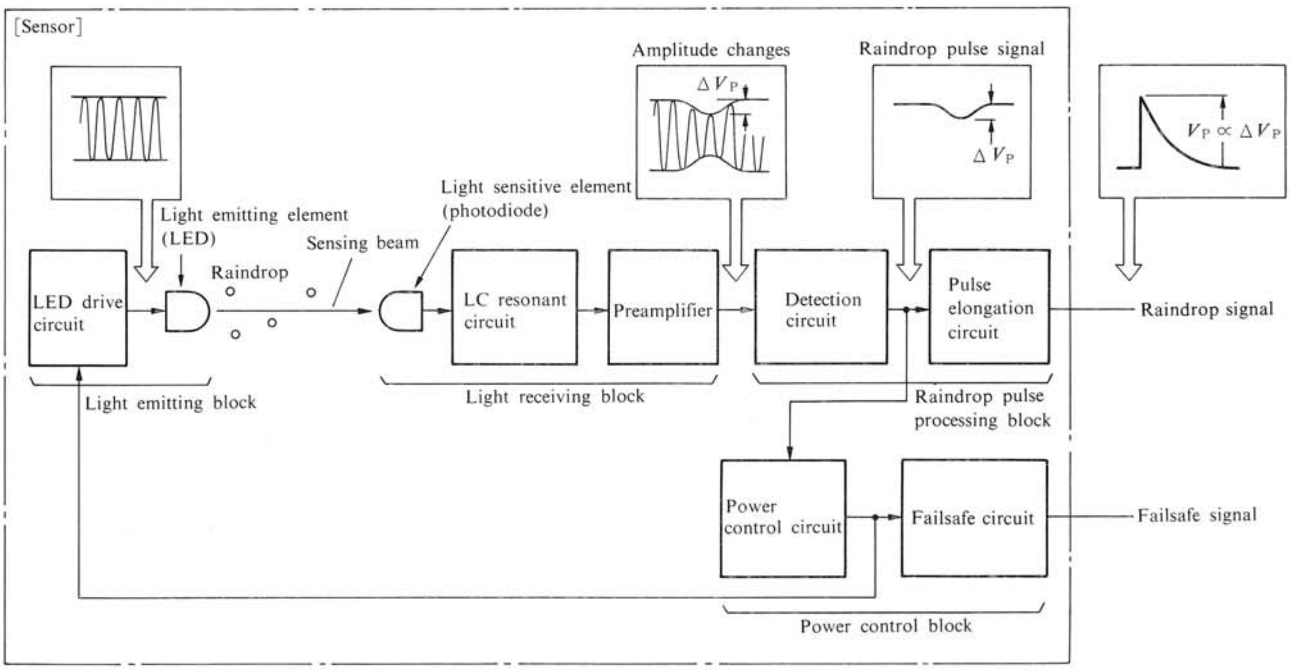


Figure 7. Sensor circuit block diagram

pulsating way by the LED driver; therefore, the emitted light can be easily distinguished from interfering light such as sunlight.

3.3.2 Light receiving block

The pulsating light from the LED is received by the light sensitive element and is converted to an electric signal. The light sensitive element is a PIN photodiode featuring quick response. Only the fundamental-frequency component in the emitted pulses is detected by the LC resonant circuit. The signal obtained is then amplified by the preamplifier. The change in the intensity of the received light which occurs when a raindrop crosses the sensing beam can be detected as the change in the amplitude of the preamplifier output. The preamplifier output amplitude change $\triangle Vp$ is proportional to the received light intensity change $\triangle P$ given by equation (1) as follows:

$$\triangle Vp = k_1 \times \triangle P \text{ ---------- } (2)$$

Where k_1 is a constant.

3.3.3 Raindrop pulse processing block

The detection circuit extracts the amplitude change $\triangle Vp$ from the output of the preamplifier in the light receiving block. The output of the detection circuit is a raindrop pulse signal. The pulse width of this signal varies depending on the car speed. For a speed of 100 km/h, the frequency of the raindrop pulse signal is about 20 to 30 kHz. A pulse elongation circuit is adopted so that the raindrop pulse signal can be distinguished from pulsating noise produced by the car; this circuit holds only the raindrop pulse signal amplitude $\triangle Vp$ corresponding to the raindrop diameter as significant information when converting the raindrop pulse signal to a low-frequency signal. The pulse elongation circuit performs both amplification and peak detection at the same time, thereby converting the raindrop pulse signal to a raindrop signal with an amplitude Vp given by the following equation and a frequency of several hertz.

$$Vp = k_2 \times \triangle Vp \text{ ---------- } (3)$$

Where k_2 is a constant.

3.3.4 Power control block

The intensity of the received light fluctuates due to contamination stuck to the light emission and/or receiving port, variations in the power of the emitted light, and deviation in the optical axis of the LED and photodiode which may occur when the sensor is assembled. This variation affects the sensitivity of raindrop detection. To prevent such sensitivity variation and eliminate the need for adjusting the optical axis at assembly, a power control circuit is adopted. This circuit always monitors the output of the detection circuit and performs feedback control for the LED drive current.

The control range of the power control circuit is determined by the intensity variation of the received light. The factors of intensity variation are as follows:

1) Contamination stuck to the light emission and receiving port

We installed the sensor on a semitrailer to study the influence of contamination, such as dust and exhaust gas, on the sensor installed on a passenger car. Figure 8 shows the results of this study. The intensity of received light was reduced by about 3 dB in about 70 days and became constant thereafter.

2) Radiant intensity from the LED

The radiant intensity is defined as the radiation power per unit solid angle in a specific direction. Variations in radiant intensity are due to variations in light power (light emission efficiency) and direction of radiation (position of chip installation). They are about ±5 dB according to the measurement.

3) Influence of temperature on LED radiant intensity

The sensor is installed on the hood of a car. It must be able to operate over a wide temperature

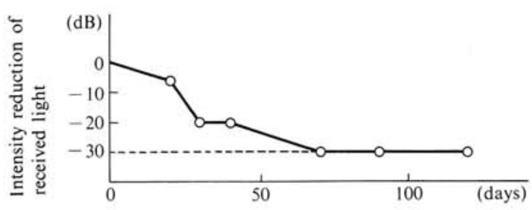


Figure 8. Contamination of a sensor installed on a semitrailer

range from about −30°C to 85°C. In general, LED radiant intensity is more likely to be influenced by temperature than is photodiode radiant sensitivity. According to the manufacturer's data, the LED radiant intensity has a negative temperature coefficient and varies within ±6 dB from the value for the ordinary temprature.

4) Influence of optical axis deviation at sensor assembly

Since the LED has a lower directivity than the photodiode, it is more likely to be influenced by optical axis deviation. By improving the accuracy in holding the light emitting and receiving elements in position, we were able to reduce the intensity of received light by about 1 dB.

The above factors are summarized in Figure 9. To prevent sensitivity variations, it is necessary to provide a compensation of about +9 dB to −15 dB for the LED drive current. Figure 10 shows the characteristics of the power control circuit provided to prevent sensitivity variations and to eliminate the need for optical axis adjustment at assembly. Even when the infrared transmissivity of the light emission and receiving ports drops about 60%, reduction in raindrop detection sensitivity is kept within 10%. Stable sensitivity is thus achieved.

Also, the sensor fails to detect raindrops when the sensing beam is completely blocked. This is probably because of snow or other matter stuck to the light emission and/or receiving port. In this event, the power control output is used to control the failsafe circuit so that the wiper can operate at a 6-second interval like a conventional fixed-interval wiper.

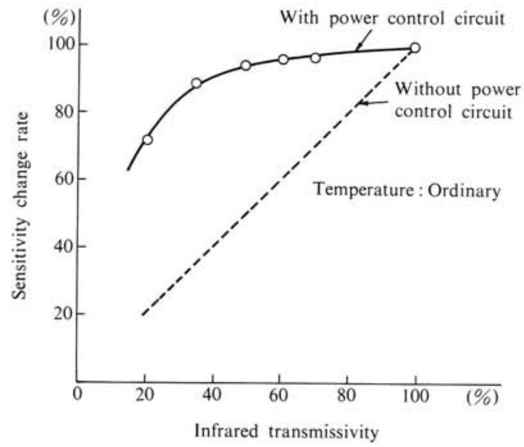


Figure 10. Relationship between infrared transmissivity and sensitivity change rate

3.4 Structure

Figure 11 shows the structure of the sensor. The requirements for the sensor structure include sensing ray transparency of the outside case, environmental resistance, vibration resistance, and waterproofing. Our main considerations are explained below.

1) Outside case: The light emission and receiving ports must be transparent. Also, design flexibility should be high. Considering these points, we selected resin as the outside case material. We chose a polycarbonate resin because of its environmental resistance — storage temperature (-40°C to 100°C), relative humidity (85% at 85°C), and resistance to chemicals such as wax and oil. We added dye-based coloring agents to

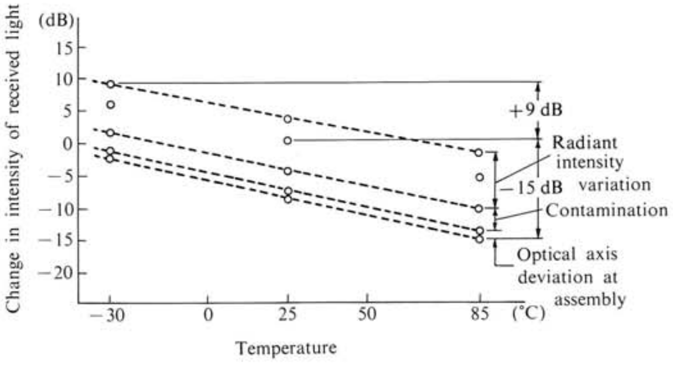


Figure 9. Dependence of received light intensity on temperature

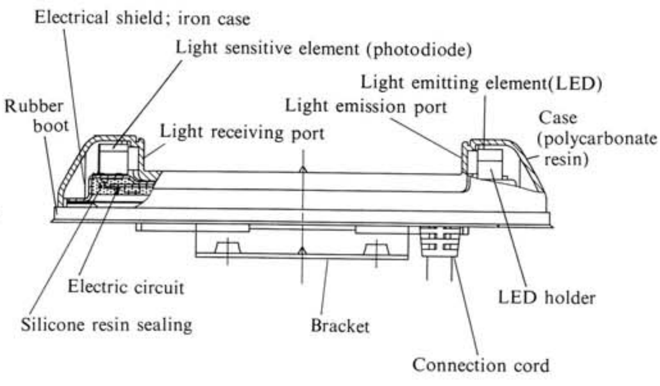


Figure 11. Senser structire

the polycarbonate resin so that visible light would be filtered out.

2) Structure of light emitting and sensitive element support: Prevention of vibration was considered when designing the light emitting and sensitive element support structure. This was because if vibration of the car deviates the optical axis of the LED and photodiode, the sensor may malfunction.
3) Electric circuit protection: The electric circuit in the sensor is composed of chips and is entirely sealed with silicon resin. Also, the entire circuit is placed in a shielding iron case to protect the circuit from electromagnetic noise coming from the car.

3.5 Position of installation

We studied the position of sensor installation by running a car with the sensor. The candidate positions were in the front radiator grill, on the hood, and on the door mirror. The difference in feeling and ease in installation was evaluated for each of these positions. As a result, we found that the distance between the windshield and sensor should be as short as possible to assure satisfactory wiper operation for conditions other than normal rainfall such as splashing from on-coming cars and water dripping down from an overpass. Considering this and ease of installation, the windshield-side of the hood was chosen.

4. Controller

4.1 Circuit

Figure 12 is a block diagram of the controller circuit. The controller contains a 4-bit microprocessor which processes raindrop pulse signals from the sensor.

The output section contains relays to drive the wiper motor. The input section is divided into sensor and car input sections. Raindrop and failsafe signals are supplied from the sensor input section. The car input section consists of the wiper motor cam switch, washer switch, and wiper switch; signals from these switches are supplied to the automatic wiper. The

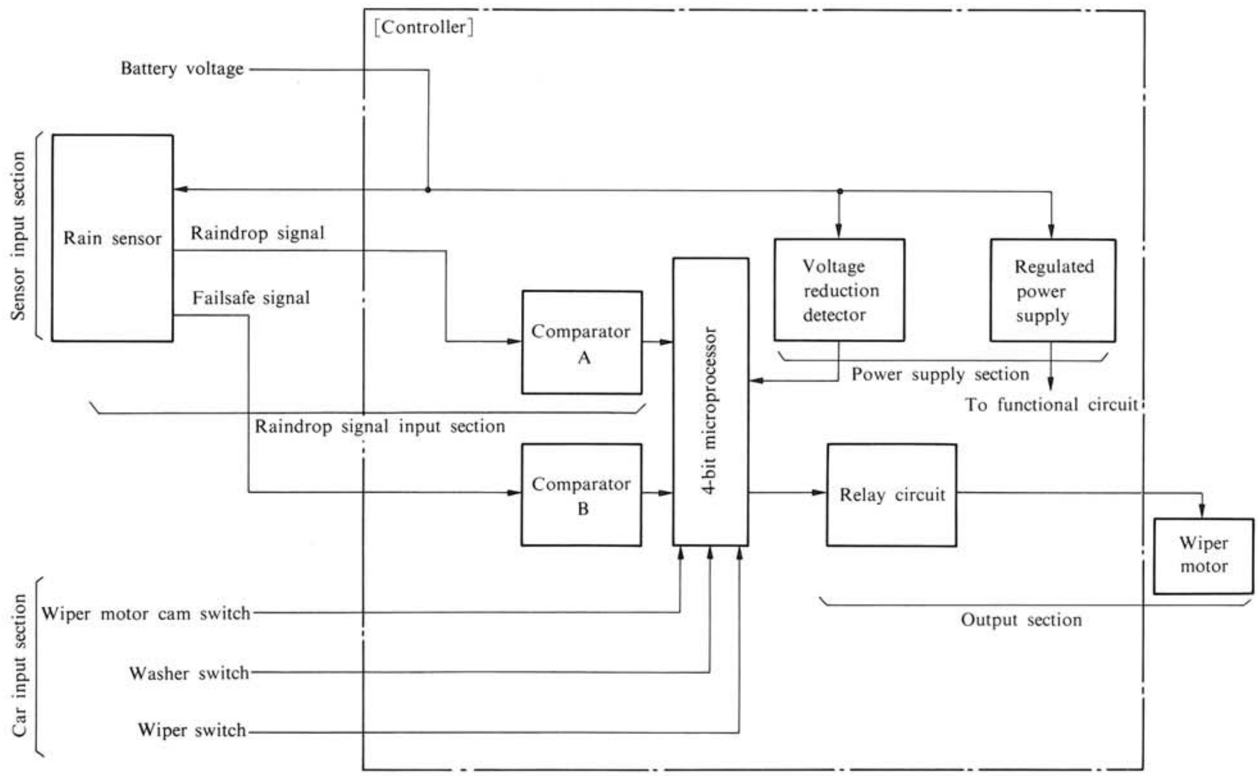


Figure 12. Controller circuit block diagram

power supply section contains a voltage reduction detector which helps reduce malfunction due to low voltage. The construction and function of each main circuit block is explained below.

4.1.1 Raindrop signal input section

The raindrop signal from the sensor is fed to comparator A, which converts the amplitude Vp of the raindrop signal into pulse-width information. This pulse-width information is read into a software counter in the microprocessor to determine the degree of rainfall.

4.1.2 Output section

The relay circuit is controlled by microprocessor output. The relay is turned on and off to drive the wiper motor. Pulse-width information corresponding to the diameter and number of raindrops is stored in the microprocessor, and is initialized each time the wiper motor is driven.

4.1.3 Power supply section

The voltage reduction detector in the power supply section detects a transient drop of the battery voltage and cancels raindrop signal read, thus preventing system malfunction.

4.2 Outline of processing

We made a study of how drivers like the windshield wipers to operate. The results are as follows: The driver feels discomfort if the wiper interval changes very much or frequently when the quantity of rainfall is constant. The driver can accept variations up to ±30%. We thus adopted a stepwise control scheme which keeps the wiper interval within variations of ±30% from the wiper interval ideal to the driver as indicated in Figure 13. When rainfall is decreasing, the wiper interval is kept constant for a certain period before gradually being lengthened to the next interval.

However, when the car exits a tunnel and encounters a sudden increase of rainfall, a sudden increase in wiper speed is required. In such a case, the system is designed so that the wiper speeds quickly responds to sudden changes.

Figure 14 illustrates wiper interval changes that occur in various conditions.

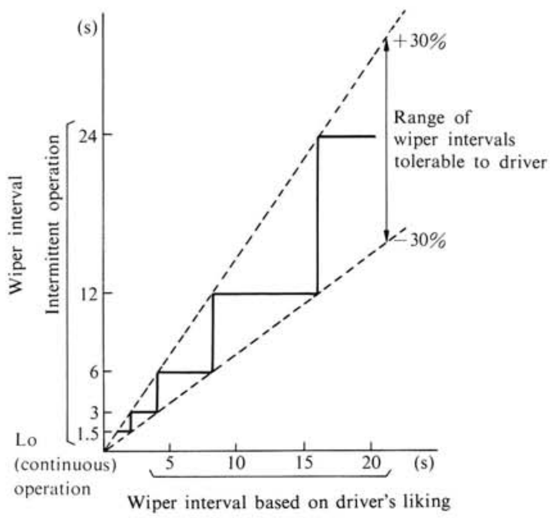


Figure 13. Stepwise wiper control

5. Evaluation using rainfall simulator

We fabricated a rainfall simulator as shown in Figure 15 so that sensory evaluation could be conducted on the system installed in car under a constant condition without the influence of actual weather. The simulator can produce rainfall conditions ranging from light rain to moderate rain when the quantity of water and the air pressure are adjusted appropriately.

The quantity of rainfall, or precipitation, was measured with Whatman paper to which methylene blue powder was stuck. When a raindrop falls on the paper, the paper turns blue. The diameter of the raindrop can be estimated from the size of the blue spot. Therefore, the amount of rainfall can be determined from the diameters and number of raindrops that fell onto the paper during a specified time. Figure 16 shows an example of comparison between spots generated by actual rain and spots generated by the rainfall simulator. This figure indicates that actual rain and the simulator produce similar raindrop diameter distributions.

Figure 17 shows the results of evaluating the system using the simulator. The results are satisfactory because the wiper interval changes in response to the rainfall.

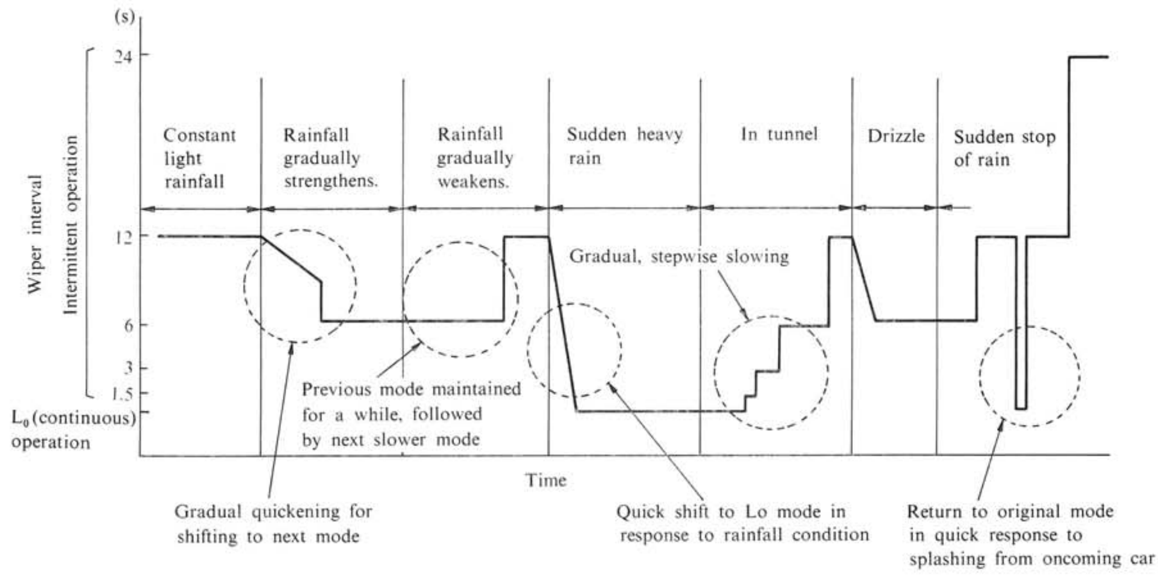


Figure 14. Changes in wiper interval

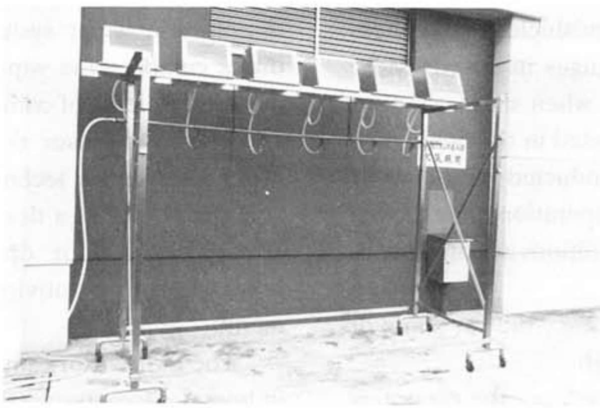
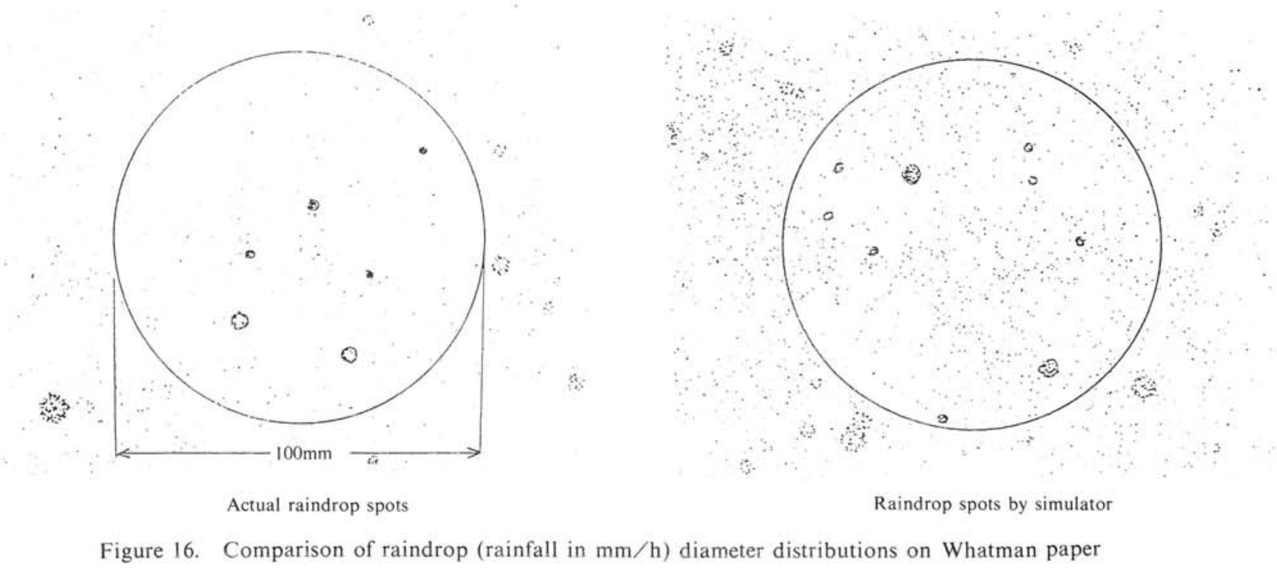


Figure 15. Rainfall simulator



Actual raindrop spots

Raindrop spots by simulator

Figure 16. Comparison of raindrop (rainfall in mm/h) diameter distributions on Whatman paper

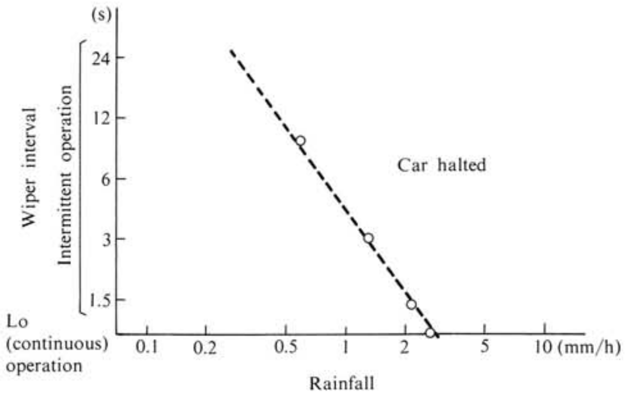


Figure 17. Results of experiment with rainfall simulator (relationship between rainfall and wiper interval)

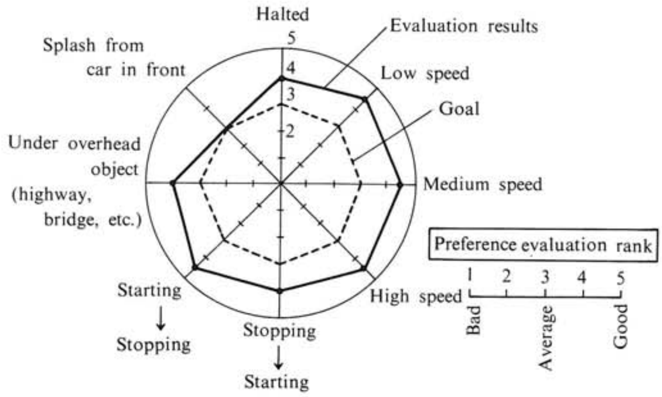


Figure 18. Results of sensory evaluation during field testing

6. Field test evaluation

When only the rainfall simulator is used, it is impossible to evaluate how the driver feels about raindrops that stick to the windshield and changes that occur in response to changes in speed. More reliable evaluation is possible when simulator tests are combined with tests conducted in the field.

Sensory evaluation was conducted for a driver's preferences concerning wiper operation under actual conditions. The evaluation conditions adopted are as follows:

① The car speed changes — e.g., the car starts or shifts gears from low to high.

② Rainfall changes abruptly — e.g., the car enters or exits a tunnel.

③ The car is exposed to fine spray from a car in front. Under each condition, actual wiper operation timing was compared with the timing the driver feels best, and the driver's satisfaction was graded on a scale from one to five.

The results are shown in Figure 18. The dotted line indicates the goal, whereas the solid line indicates the average of the driver's satisfaction. The goal was set up considering difference in feeling between individual drivers. The goal thus represents an average of general drivers.

The results of the tests suggest that the automatic wiper can achieve the goal in any condition and has satisfactory performance.

7. Conclusion

We have developed an optical automatic windshield wiper control which is an improved version of intermittent wiper systems. This wiper system reduces cumbersome wiper operations and improves the driver's level of comfort.

The rain sensor developed for the automatic wiper uses optics technology. The rain sensor has been marketed as a device suitable for use in harsh environments. Our optical system features high accuracy, high sensitivity, and non-contact measurement.

The rain sensor can also be used as a component in home automation systems because it can detect a sudden rain and notify people in the house. Other possible applications are as smoke sensors and high-performance photoelectric switches. We shall continue to study new applications and themes.

Reference

1) Skolnik, M. I.: "Radar Handbook," McGraw-Hill, USA (1970)

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