Development of Next-Generation Image Processing Vehicle Detector

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A Novel image processing vehicle detector has been developed and released to the market. We have resolved some defects seen in conventional detectors, most of which are caused by weather changes or lack of resolution. We have adopted two approaches: the improvement of algorithms for vehicle detection, and the use of a high resolution camera. These improvements have enabled the product to provide stable performance all day throughout the year and also to detect vehicles far from the camera more precisely than conventional NTSC cameras. Our product can be used not only as a traditional traffic flow detector but also as a next-generation detector such as one for the driving safety support system (DSSS). In addition, the product is upgradable due to its hardware and software scalability.

Keywords: sensor, video-image, vehicle, detect

1. Introduction

Recent years have seen growing concern regarding global warming and other environmental issues. Japan, the Unites States, EU and other nations have formulated various national projects and are competing in technology development to reduce greenhouse-effect gas emissions in the transport sector, specifically in the road traffic field.

In Japan, meanwhile, the number of traffic accident deaths has decreased to less than 5,000 per year, while the number of injuries is approaching one million per year. In the United States, road traffic-related deaths exceed 30,000 per year. Concern is also increasing in regard to safety as well and the environment.

Under these circumstances, Sumitomo Electric Industries, Ltd. has for some years now addressed both environmental and safety issues from an infrastructure perspective.

Particularly in regard to safety, the National Police Agency developed the driving safety support system (DSSS). DSSS demonstration tests have been conducted and pilot projects have been implemented. In DSSS, infrastructure and vehicles coordinate to provide every vehicle approaching an intersection or poor visibility section with traffic light information and information on nearby vehicles. The system issues advice or warning to the driver, using the vehicle's navigation system or an announcement system.

Meanwhile, the automatic incident detection system (AID) has also been developed, which is a system designed to detect non-moving or low speed vehicles on expressways, including inside tunnels, and to provide users with relevant data via road information boards.

In both systems, road detectors play an important role in accurately detecting vehicles on the road. Since 1992, Sumitomo Electric has commercialized image-processing vehicle detectors (image detectors) incorporating a camera.

The advantages of the image detector include: (1) A single unit is capable of simultaneously measuring traffic flows (number of vehicles, speeds and vehicle classes) in multiple lanes; (2) It is small, easy to install, and excellent in terms of the urban landscape; (3) It requires no special in-vehicle device; and (4) Its video image capability enables operators to keep track of traffic conditions in real time.

A drawback of the image detector is that accuracy occasionally diminishes due to variations in the external environment, such as weather and sunshine conditions or low resolution in distant zones.

Through years of image detector research and development, however, Sumitomo Electric has overcome this problem. We have succeeded in commercializing an image detector that is: (1) robust in performance under variable environmental conditions; (2) capable of carrying out measurements in a wide range; and (3) commonly usable with conventional traffic flow measurement systems and next-generation systems such as DSSS. Shipping of the image detector to some of our customers has already commenced.

This paper reports on the recently commercialized image detector as to its features, configuration and field test results.

2. System Configuration

The image detector comprises a camera unit and control unit, as shown in **Fig. 1**. The camera unit is normally installed on the road, and the control unit on the roadside. If images are to be transmitted from the camera unit to the control center, the control unit may be installed in the control center.

Video images captured by the camera unit are input to the control unit, which processes the image data for vehicle detection.

Measurement results obtained by the image detector are sent to different destinations depending on the use, which primarily comprises the following three:

(1) Nearest traffic light and road information board
(signal control and information provision)
(2) Traffic control center
(signal control and information provision)
(3) In-vehicle device (DSSS)

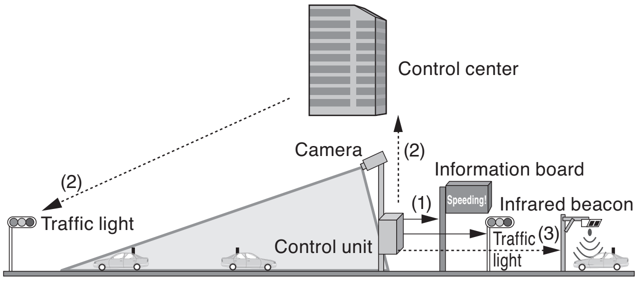

Fig. 1. System configuration

3. Development Considerations

3-1 Existing problems

One general problem with image detectors is the decline in detection accuracy under certain conditions.

For example, when there is a drastic change in sunshine or when it is raining, headlight beams reflected by road surfaces can temporarily degrade detection accuracy. Vehicles distant from the camera can be too small in the image, and their motion rate too low, to be detected. Under these conditions, image detectors may temporarily fail to meet their product performance specifications.

Meanwhile, we are considering the incorporation of continual radio communications in DSSS, to keep track of vehicle movements widely in real time. Accurate recognition of vehicle movements requires correct real-time vehicle location information. Conventional detectors used for traffic flow measurement are inadequate for that purpose.

3-2 Development goals

In response to the above-mentioned circumstances, Sumitomo Electric set two goals: (1) to maintain stable measurement accuracy on a 24-hour, 365-days-a-year basis, with a system strongly resistant to environmental variations and (2) to provide high positional accuracy in a wide range (approx. 100 m). Measurement accuracy targets were set for each application, as shown in **Table 1**.

Table 1. Application-specific performance targets (permissible errors)

	Number of vehicles	Speed	Vehicle classification	Positional accuracy
Traffic flow measurement detector	Relative error: 10%	Relative error: 10%	Relative error: 20%	
DSSS detector	No-detection rate: 5% Detection error rate: 10%	Error: ±10 km/h		±10 m

3-3 Development plan

To achieve the aforementioned goals, we promoted both software and hardware development.

With the first goal in mind, we primarily carried out software development. Using field-collected video data obtained through Sumitomo Electric's years of experience in image detector development, we improved the measurement algorithm.

Our image detectors have been shipped throughout Japan from Hokkaido in the north to Okinawa in the south, and in overseas markets, to Southeast Asia. Our database contains a vast store of video, collected under various environmental conditions, varying from images of snow and fog to tropical squalls. Using this video database, we repeatedly improved and tested the measurement algorithm.

To achieve our second goal, we focused our development efforts on hardware. Newly added to the lineup was a high-definition camera (full HD) with higher distance resolution per pixel than the standard definition camera (NTSC: National Television Standards Committee). These two approaches are explained below.

4. Measurement Algorithm

First, the vehicle measurement algorithm was developed, as follows. The basic process of the measurement algorithm is to: (1) extract characteristic points from images captured by cameras (extraction of characteristics); (2) identify vehicle zones by many groups of characteristic points (vehicle recognition); and (3) track vehicles (vehicle tracking). Ultimate output data containing speed and vehicle number information is computed from the results of tracking obtained through (3). This paper primarily explains (1) extraction of characteristics and (2) vehicle recognition.

4-1 Extraction of characteristics

Typical characteristics found in collected images include differences (background subtraction) between images without vehicles (background images) and incoming images, and differences (temporal subtraction) between previous images and incoming images. Although background subtraction enables accurate extraction of vehicle body zones, it is difficult to ensure stable, periodic updating of the correct background image. Temporal subtraction is effective for detecting moving objects, but fails to stably detect non-moving vehicles.

To resolve these problems, it is good practice to use characteristics known as the increment sign[(1)], which focuses exclusively on variations in brightness between adjacent pixels. The increment sign simply represents the intensity relationships between adjacent pixels, rather than the absolute brightness of individual pixels. Accordingly, the increment sign is inherently immune to overall brightness variations in the entire image caused by sunshine changes. Even when a shadow is present in a scene, the code of the shaded section shows little change in comparison with scenes with no shadows. This feature reduces the chance of erroneously detecting the shadow cast by a vehicle as an actual vehicle. The increment sign, being highly immune to the effects of environmental variations, in combination with background and temporal subtractions enables more stable extraction of characteristics.

4-2 Vehicle recognition

The goal of vehicle recognition is to label groups of characteristic points (increment signs) obtained through the processes explained in 4.1 and sort the labels into vehicle and other categories. In one vehicle recognition technique, many characteristic vehicle patterns are provided in advance for the system to learn, so that the system can determine whether the characteristic pattern of the incoming data resembles one of the learned characteristic vehicle patterns. However, it is generally difficult to provide beforehand supervised data that is commonly valid in all fields.

The technique presented in this paper uses perspective projection. Using data measured at several points on the road when the camera is installed, a relational expression is determined between the camera and road plane (perspective projection matrix). As is well known, perspective projection projects points defined in a coordinate system (world coordinate system) whose origin is an arbitrary point on road plane, uniquely onto the image plane as sets of coordinates (image coordinates).

In general, perspective projection expresses dimensional reduction from 3D to 2D in the image generation process, and as such, is irreversible transformation. However, if projection is limited to any plane expressed in the world coordinate system, it is possible to back-project onto that plane points contained in an image. Consequently, by selecting a desired plane as the road plane, points from an image can be back-projected onto the road plane.

On this basis, the groups of characteristic points obtained in the preceding section are labeled, carefully discriminating noise components. All characteristic points deemed to correspond to the front (or rear) parts of vehicles are then back-projected onto the road plane. Possible vehicle presence zones are then assigned to all back-projected points. In each zone, 'probability of vehicle presence' is determined. In this paper, "probability of vehicle presence" refers to an overall score calculated from the number of characteristic points, restrictions resulting from assuming a vehicle to be a rigid body, and other factors. Zones with a score at or above a given threshold are identified as vehicles. It is even possible to determine vehicle size by the score. Eventually, the system can determine vehicle classes and other features to indicate what vehicles are present in the vehicle presence zones.

5. High-Definition Camera

This section explains high-definition cameras. Full HD offers a resolution of 1920 horizontal pixels × 1080 vertical pixels, the number of pixels being more than five times that of the NTSC system. Accordingly, a finer picture is produced with a high-definition camera than with an NTSC camera in the same position when taking a picture of a distant vehicle. Consequently, high-definition cameras offer greater capacity for vehicle detection.

Moreover, at the same positional accuracy, the high-definition camera is capable of measuring to a greater distance than is possible with the NTSC camera, since the distance resolution per pixel is higher in the former. For example, under the standard image detector installation conditions established by Sumitomo Electric, the NTSC camera would identify vehicle positions with a resolution of less than 10 cm per pixel up to approximately 36 m distant from camera, while the high-definition camera would do the same up to approximately 56 m.

Furthermore, the full HD specification is taking a dominant position in home-use audio-visual equipment, entailing falling prices of imaging devices and recording equipment. It is expected that the prices of high-definition industrial cameras will also drop in the future. Taking these factors into account from a general perspective, we envisioned that high-definition cameras will be usable for systems that offer high positioning performance.

6. Product Features

We have developed products that incorporate the above-described measurement algorithm, ensuring usability for both NTSC and high-definition cameras. The features of the product are explained below. **Figure 2** shows equipment configuration. Exterior and specifications are shown in **Photo 1** and **Table 2**, respectively.

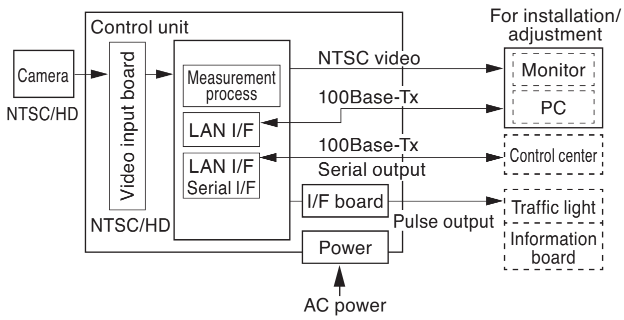

Fig. 2. Equipment configuration

Photo 1. Equipment exterior

Table 2. Specifications

Weight		Camera unit : 4 kg max.
		Control unit : 6 kg max.
Dimensions (mm)	Camera unit	95.5 (H) × 124 (W) × 335 (D)
	Control unit	380 (H) × 215 (W) × 110 (D)
Power		100 V AC ± 10%, 50 Hz
Power consumption		50 VA max.
Operating temperature		−10°C to +50°C
Operating humidity		40% to 90%
Cable length between control unit and camera		100 m max.

The NTSC or high-definition camera is selected according to need. The control unit selects only the type of video input board that supports the selected camera. The processing board has software designed to automatically recognize which camera has been selected. The high-definition camera is used in systems that require high positional accuracy, such as DSSS. For systems controlling traffic lights or providing information, the low-cost NTSC camera is used.

6-1 Processing board

Recently developed products include a roadside image detector for traffic flow measurement and a DSSS image detector. Sumitomo Electric also offers various other image detectors; for example, we have detectors for the occurrence of abnormal events, such as a non-moving or low speed vehicle in a tunnel, and detectors for counting the number of vehicles on an expressway and measuring their average speeds. In these systems, video captured with cameras on the road is in many cases sent to indoor facilities, such as an electrical room, for intensive image processing, with many processing boards stored in racks. In addition, in recent years, some video data input to video processing racks are MPEG compressed, requiring data decoding before image processing. Accordingly, Sumitomo Electric's image detectors require many types of processing boards, in terms of hardware variance in board shape and display LED, as well as in the orientation and positioning of connectors used for connecting with the adjustment PC, and in data processing capacity requirements. Conventionally, we have developed dedicated processing boards to meet each need, requiring development expenses and time.

Meanwhile, processors advance continuously; in recent years it is not unusual for miscellaneous electronic components to be discontinued in only a few years, ultimately necessitating hardware design change. Moreover, when image processing is done indoors, the system may in some cases be constructed conveniently, using a commercially available PC rather than a dedicated outdoor-duty processing board. The traditional practice has been to change software in response to each of these hardware changes, which requires development cost and time.

As a solution to these hardware and software problems, Sumitomo Electric developed a common ITS equipment platform[(2)], which was used to reduce the development cost of newly developed products and enable their quick release.

The newly developed processing board has more than three times the data processing capacity of our previous products, to enable use of the aforementioned measurement algorithm.

Figure 3 shows the configuration of our proprietary processing board that has been newly developed. The board's control and image processing CPUs are connected via PCI bus, enabling the fast data transfer required for MPEG video input and the like. NTSC or full HD mode video output from the camera undergoes A-D conversion, passes through the image-processing CPU and is transferred to the image memory. The image-processing CPU processes the image in the image memory. Measurement results are then sent via PCI bus to the control CPU, which converts the results to pulse, serial or packet signals, according to the need, and sends the data to an external device.

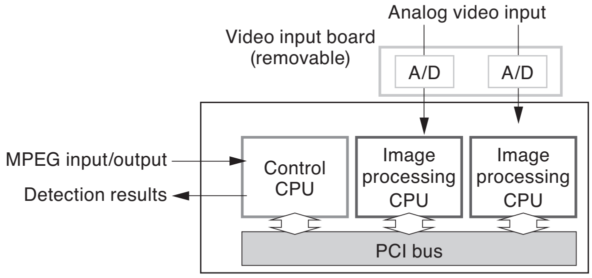

Fig. 3. Processing board configuration

6-2 Other features

In commercializing a product, equipment cost is an important factor, as are features and performance. We have reduced cost and achieved thorough board miniaturization by increasing board density and using a general-purpose low-cost housing approximately 70% smaller than our previous products.

Since it is installed on the road, the camera unit should be small and light from the perspective of urban landscape aptness and installation simplicity, such as additional installation to existing posts. As with the control unit, therefore, we miniaturized built-in boards and employed a small camera. The result is a camera housing approximately one-third smaller than our previous products.

Both NTSC and high-definition cameras offer a zoom feature for responding to various application and installation location requirements.

The front glass of the camera has a heater for defogging, although heat generated by the heater can raise the temperature in the housing, possibly causing damage to the camera or other devices. Our solution was to turn off the heater at air temperatures above which fogging is unlikely.

The camera housing was also modified. Vehicle detection by image processing is affected by such factors as rays of the rising or setting sun entering the camera, or dirt on the front glass of the camera. To minimize the effects of these factors, we used incident sunlight and wind velocity simulation results to develop our original extra hood, which limits incident sunlight and the volume of wind striking the front glass. In addition to the basic sun hood, the extra hood was mounted to locally cover the front glass. In the middle of winter, or when it snows, heat generated by the heater escapes due to strong chilly winds striking the front glass, resulting in loss of the defogging effect. The extra hood is also effective in resolving this problem.

7. Test Results

Using the video database described earlier, we tested the performance of the newly commercialized image detector on the basis of the above-mentioned development. **Figure 4** shows the NTSC camera's traffic flow measurement accuracy (%). The horizontal axis represents numbers assigned to scenes with environmental variations. Average accuracy is plotted on the vertical axis. **Figure 5** shows positional errors (cm) of the high-definition camera used for wide-range measurement (100 m from camera). The horizontal axis represents the same variable as in **Fig. 4**, while the vertical axis indicates average positional error for each scene.

The results demonstrate the system's high accuracy in traffic flow measurement, unaffected by time of day or weather. Use of the high-definition camera reduces the average positional error to approximately 2.8 m, even in a wide measurement area. The maximum positional error caused by external environmental variations is within the specification limits, the accuracy being practically acceptable.

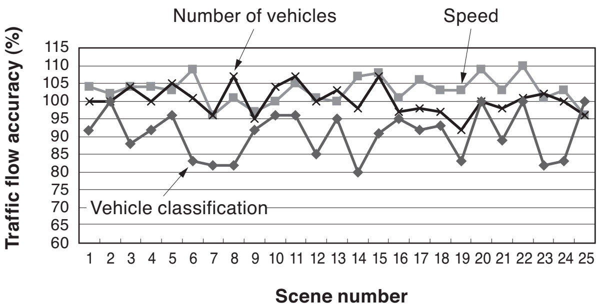

Fig. 4. Traffic flow measurement accuracy of NTSC camera

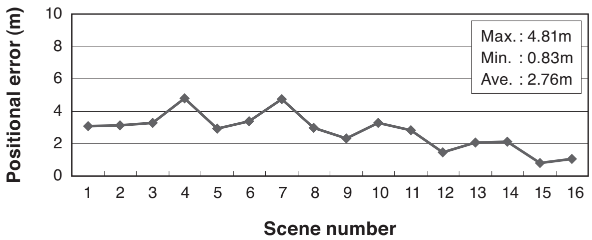

Fig. 5. Positional error of high-definition camera

8. Conclusion

We have alleviated the shortcomings of our current products and have developed and commercialized an innovative image detector that is compatible with next-generation systems.

Regarding software, we have developed a new measurement algorithm, which is strongly resistant to environmental variations. This minimizes accuracy degradation due to changes in sunshine/shadow and enables stably accurate operation 24 hours a day, 365 days a year.

Moreover, because the image detector has both an NTSC camera and a high-definition camera, it ensures high positional accuracy over a wide measurement range (100 m from camera).

In terms of hardware, the small control unit housing reduces cost. The camera unit is two-thirds the size of our previous products. Furthermore, a glass heater and our original extra hood have been provided as measures against setting sun glare, soiling of glass and other issues. The dedicated processing board design, based on Sumitomo Electric's proprietary platform, provides functional and performance scalability.

As a result of increasing environmental and safety concerns, demand is expected to grow for road detectors of increased capability and performance. The detector described in this paper is able to meet such needs flexibly, in terms of both hardware and software.

9. Acknowledgments

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