Development of Non-Stop Toll Collection System

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The Non-stop Toll Collection System can ease traffic congestion, reduce cost of manpower and improve customer service by cashless tolling. Also, it can bring about environmental improvements by reducing the exhaust gas and noise emitted as vehicles start or accelerate from toll plazas. Therefore, its application to toll roads has been increasing especially in foreign countries. This report covers the elemental technology and system technology needed for the Non-stop Toll Collection System and the result of system operation tests in Malaysia and Singapore. Mitsubishi Heavy Industries, Ltd. (MHI) started the development of this system in 1984, and has received orders for the system from the countries mentioned above. The system employs elemental technology and system technology using radio frequency communication (RF communication) and image processing obtained by many years of research.

1. Introduction

The aim of the electronic toll collection (ETC) system is to collect tolls at toll plazas by RF communication without requiring the passing vehicles to stop at the plazas. The system is expected to improve the environment by reducing emissions and lowering engine restarting noise, and to bring about economic effects by saving fuel and shortening driving time. This system, which has been already installed widely in Europe and America, has recently been planned and introduced in Asia, and use of the system is becoming a global trend. MHI started its research and development in 1984, and received orders for the ETC system from Malaysia, and also for an electronic road pricing (ERP) system from Singapore as a toll collection system which limits traffic flow into the urban area.

This paper gives an outline of the ETC system and elemental technologies including the RF communication, image processing, and system integrating. As practical examples, trial operation reports of the systems for Malaysia and Singapore are also included.

2. Outline of ETC system

The ETC system allows vehicles to pass without stopping or manual operation by collecting the toll through RF communication between a roadside antenna installed at the toll plaza and an RF communication unit mounted on the vehicles. The system consists of the antenna for RF communication, antenna controller, vehicle presence detector for detecting the presence of vehicles on the lane, equipment to block the passing and capture the image of vehicle with invalid onboard equipment (OBE), and a lane controller for integrating and controlling these devices. The ETC system may be classified into the single-lane ETC system and multi-lane ETC system depending on the lane type of the toll plaza. The former collects tolls on every lane as in existing toll plazas, and basically performs a sequential transaction for each vehicle. The latter collects tolls from a number of vehicles simultaneously traveling along several lanes, as on an expressway. Each system is described below.

2.1 Single-lane ETC system

2.1.1 System configuration

The single-lane ETC system is applied in place where the lanes are completely separated, as in existing toll plazas, and is designed to collect toll from each vehicle on every lane entering the toll plaza. An example of this system configuration is shown in Fig. 1. As shown in the diagram, the single-lane system is composed of a roadside antenna, a vehicle presence detector, indicator and others, but the toll collection

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*2 Takasago Research & Development Center, Technical Headquarters
*3 System Technology Center, Electronics Research & Development Department

Mitsubishi Heavy Industries, Ltd.
function on lane differs between the toll lane of the open system collecting the same toll from each type of vehicle, and the closed system collecting different tolls depending on the traveling distance and vehicle type. Thus, the system configuration also varies with the lane of the open system, the entry and exit lane of the closed system.

2.1.2 System functions

In most instances of the single-lane ETC system, the ETC equipment is additionally installed to existing manual toll plaza, and the system is therefore often integrated with the existing toll collection system equipment (vehicle presence detector, lane barrier, indicator, and other lane control devices having interface between the roadside equipment and the host equipment for totalizing the tolls).

As mentioned above, these existing toll system arrangements vary with the lane type—e.g., open system and closed system (entrance and exit toll plaza)—and also the toll plaza type. The basic functions of the single-lane ETC system are:

- Detection of vehicle entry, and start of RF communication
- Toll collection by RF communication with OBE (writing and reading of entrance toll plaza number, time, and collection of toll)
- Display of collected amount
- Detection of vehicle passage
- Capturing the image of license plate number of vehicle having invalid OBE

2.2 Multi-lane system

2.2.1 System configuration

The multi-lane ETC system is a system applied in place where a number of vehicles travel on several lanes simultaneously as on the main lanes of a tollway, and is designed to handle a number of vehicles entering the toll plaza simultaneously.

An example of this system configuration is shown in Fig. 2. As shown in the diagram, the multi-lane system is composed of the equipment installed on a gantry straddling several lanes, such as several roadside antennas, vehicle presence detectors, a camera for capturing the image of vehicle with invalid or no OBE.

2.2.2 System functions

In the multi-lane ETC system, since the ETC equipment is installed on the main lane of the tollway, the traveling speed of the vehicle is fast, and it is necessary to determine the position of the moving vehicle on the lane, unlike the single-lane system installed on the toll plaza lane.

Therefore, there is a need for both high-speed processing to deal with the vehicles traveling at high speed on several lanes simultaneously, and short-range communication band of roadside antennas for identifying the vehicles from which toll are collected. The functions of multi-lane ETC system are given below.

- Toll collection by RF communication with OBE (writing and reading of entrance toll plaza number, time, and collection of toll)
- Detection of vehicle passage position on the lane by vehicle presence detector
- Locating the position of the vehicle communicated with the antenna
- Capturing the image of license plate number of vehicle having invalid OBE by the camera at the detected position

3. Elemental technologies of ETC

Construction of ETC system requires various elemental technologies including RF communication technology. It also requires a system technology to integrate these elemental technologies. As principal elemental technologies of the ETC system, the RF communication technology, vehicle detection technology, and technology for enforcement are briefly described below.

3.1 RF communication technology

3.1.1 Requirements for RF communication

(1) High reliability

Since financial information is handled in the ETC system, high reliability is required in the RF communication. Usually, the data bit error rate is required to be $1 \times 10^{-4}$.

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Fig. 2 Example of system configuration of multi-lane ETC system
An example applied to main lane of expressway is shown.
<table>
<thead>
<tr>
<th>Item</th>
<th>Specification</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roadside antenna</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frequency band</td>
<td>2.450 MHz band*</td>
<td>• 1 Frequency band and output vary with each local situation</td>
</tr>
<tr>
<td>Output</td>
<td>300 mW or less*</td>
<td></td>
</tr>
<tr>
<td>Polarization</td>
<td>Circularly polarized wave</td>
<td></td>
</tr>
<tr>
<td>Data transmission</td>
<td>600 kbps or more*</td>
<td>• 2 Varies with the applicable system</td>
</tr>
<tr>
<td>speed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Modulation method</td>
<td>ASK*</td>
<td>• 3 Amplitude shift keying</td>
</tr>
<tr>
<td>Communication area</td>
<td>3 m (transverse direction)× 4 m (traveling direction)*</td>
<td>• 4 Supposing vehicle mounting height to be 1 m</td>
</tr>
<tr>
<td>Onboard equipment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Method</td>
<td>Passive method (backscatter)</td>
<td></td>
</tr>
<tr>
<td>Modulation method</td>
<td>FSK*</td>
<td>• 5 Phase shift keying</td>
</tr>
</tbody>
</table>

(2) Limitation of communication area

To obtain the high reliability mentioned above, sufficient radio transmission intensity must be provided, but if the antenna output is too high, it may cause interference with the antenna of the adjacent lane or communication with the vehicle ahead or behind by mistake. For this reason, the directivity of antenna must be controlled and the communication area must be limited. The communication area of roadside antennas used in this system is about 3 m × 3 m (transverse direction × traveling direction), corresponding to the size of a vehicle.

(3) High speed data transmission

To assure sufficient reliability and to transmit and receive a huge volume of data even in such a limited communication area, high speed data transmission is needed. The data transmission speed is determined by the vehicle speed and the data volume, and often required to be more than 500 kbps.

3.1.2 Main specifications of RF communication

For data communication of the ETC system, infrared ray communication and RF communication are considered to be the media that satisfies such requirements. We employ RF communication in semi-microwave band or microwave band, because they are less affected by the dirt on antennas and so on.

An example of the specifications of this RF communication equipment is shown in Table 1.

3.2 Vehicle detection technology

3.2.1 Requirements for vehicle detection

(1) High reliability

Similar to the RF communication technology mentioned above, in the ETC system, high reliability is also required for vehicle detection. The vehicle detection error rate is often required to be 1 × 10⁻³ or less.

(2) Separation of vehicles

It is necessary to separate vehicles traveling bumper to bumper or side by side accurately, and to detect the position and the number of passing vehicles correctly. Usually, the ability to detect vehicle separation is required to be several hundred millimeters or less.

(3) Dealing with vehicles traveling at high speed

To detect and identify the vehicles on the lane accurately, high-speed response of sensor and high-speed processing are required. It is particularly important to detect vehicles travelling at high speed on the main lanes of tollways.

3.2.2 Main specifications of vehicle presence detector

There are various methods for the vehicle detection, such as optical sensors, loop coils, treadles and others. As an example applicable to both the single-lane and the multi-lane system, specifications of overhead type vehicle detector are shown in Table 2.

<table>
<thead>
<tr>
<th>Item</th>
<th>Specification</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensor unit</td>
<td>One-dimensional camera</td>
<td>• 1 Varies with the applicable system</td>
</tr>
<tr>
<td>No. of pixels</td>
<td>2048</td>
<td></td>
</tr>
<tr>
<td>Driving clock</td>
<td>8 MHz</td>
<td></td>
</tr>
<tr>
<td>Detecting range</td>
<td>4000 mm (transverse direction)</td>
<td></td>
</tr>
<tr>
<td>Accuracy of separation</td>
<td>250 mm (transverse direction and traveling direction)*</td>
<td></td>
</tr>
<tr>
<td>Control unit</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Response time</td>
<td>30 ms or less</td>
<td></td>
</tr>
</tbody>
</table>

3.3 Technology for enforcement

Since the aims of the ETC system are to realize an automatic toll collection at toll plazas and to pick up invalid vehicles, it is necessary to install the enforcement devices such as lane barriers and cameras. Requirements and specifications for enforcement are described below.

3.3.1 Requirements

(1) Accurate detection of invalid vehicle

At the toll plaza, since vehicles with no or invalid OBE and vehicles with normal OBE travel together successively or adjacently, it is necessary to detect with accuracy the invalid vehicles only. Cameras for capturing the image of invalid vehicle must have sufficient resolution and illumination to be able to capture the image of high quality.

(2) Dealing with vehicles traveling at high speed

To detect vehicle traveling at high speed on the main lane of tollway, the vehicle sensor is required to have high-speed response and high-speed processing.

3.3.2 Main specifications of equipment for capturing images of invalid vehicles

Equipment for enforcement applied in the ETC system includes lane barriers and cameras. In view of the non-stop toll collection, which is the principal part of the ETC system, the camera is appropriate. The camera specifications are shown in Table 3.

4. ETC system technology

For the ETC system, together with the elemental technologies, such as RF communication technology and vehicle detection technology mentioned above, a system technology
Table 3 Specifications of equipment for capturing the image of invalid vehicle

<table>
<thead>
<tr>
<th>Item</th>
<th>Specification</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensor unit</td>
<td>CCD camera</td>
<td></td>
</tr>
<tr>
<td>Visual field</td>
<td>2500 mm × 2 500 mm</td>
<td></td>
</tr>
<tr>
<td>No. of pixels</td>
<td>1 024 pixels × 1 024 pixels</td>
<td></td>
</tr>
<tr>
<td>Resolution</td>
<td>2.5 mm/pixel</td>
<td></td>
</tr>
<tr>
<td>Control unit</td>
<td>Image compression time</td>
<td>500 ms or less†</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 At image compression rate of about 1/10.</td>
</tr>
</tbody>
</table>

for integrating these elemental technologies is necessary to realize the functions of toll collection and detection of invalid vehicle.

This system technology performs sequential transaction for each vehicle in the single-lane system, but an advanced system technology is needed in vehicle identification and others on the lanes permitting coexistence of vehicles having no OBE.

On the other hand, in the multi-lane system, in order to handle a number of vehicles traveling on several lanes simultaneously, an advanced system technology is required to identify the position of the vehicle communicated with the antenna, to identify invalid vehicles and so on.

Requirements for the system technology are summarized below.

(1) Single-lane ETC system
- Accurate and smooth execution of vehicle sequential transactions (avoidance of reversed processing order and so on)
- Integration of existing equipment, if any
- Avoidance of radio interference with adjacent lanes

(2) Multi-lane ETC system
- High-speed processing to deal with a number of vehicles travelling at high speed simultaneously
- Locating the traveling position of the vehicle communicated with the antenna
- Avoidance of radio interference with adjacent antennas

Although the equipment construction of the ETC system varies with the required specifications, a more advanced system can be constructed by adding functions, such as license plate number detector and vehicle classification, to the system configuration mentioned above.

5. Examples of trial operation

5.1 Trial operation of ETC system in Malaysia

5.1.1 Outline

As an example of a single-lane ETC system application, the ETC system in Malaysia is described. In Malaysia, a non-stop toll collection system, which takes the place of the conventional manual toll collection, was planned to install. The trial operation of the system was conducted on North Klang Valley Expressway from November 1994. In this operation, in order to verify the effect of the ETC system, the OBE was distributed to about 2 000 vehicle drivers including those other than the parties, and the test was continued for two months. MHI received the order for this trial system in March 1994. After this trial, we also received orders for the installation of ten toll plazas and 25 000 units of the OBE for commercial operation.

An outline of the trial system is given below.
- Service district: From Subang to Jalan Duta
- Toll system: Closed system
- Number of lanes: (1 ETC entry lane/1 ETC exit lane) × 2 toll plazas; by modification of the existing toll plazas and lanes
- Payment system: Pre-paid system
- OBE: One-piece type

5.1.2 Effect of ETC system

To investigate the effect of the ETC system, in the trial operation, the processing time for one lane and the number of vehicles using the ETC lanes were measured. The on-lane processing time by ETC system was found to be about one third of manual collection, and a notable effect of the system was confirmed. The number of users on the daily average amounted to about 1 600 vehicles in the total of two toll plazas, and the rate of use by the 2 000 OBE users was very high. It also ensured that the convenience of the system was widely approved by the users.

(1) Processing time at exit lane
- Manual toll collection lane: 14.7 s/vehicle
- ETC lane: 4.1 s/vehicle

(2) Number of vehicles
- Subang toll plaza (exit lane): Approx. 700 vehicles/day
- Jalan Duta toll plaza (exit lane): Approx. 900 vehicles/day

5.2 ERP system in Singapore

5.2.1 Outline

As an example of the multi-lane ETC system application, the electronic road pricing (EPR) system in Singapore is described. Road pricing, a system to charge vehicles for entering the city, is intended to limit the volume of traffic entering, and differs from the toll collection on the tollway. In Singapore, the license system was introduced in 1975 as a road pricing system to limit the traffic flow into the city.

This system involved problems in the purchase procedure of licenses and the allocation of inspectors. To solve such problems, it was planned to introduce an electronic road pricing system by RF communication.

This project was offered by international tender in 1991. Ten consortia applied and three of them were chosen, and after the evaluation tests conducted in 1994 and 1995, MHI's system as shown in Fig. 3 was finally adopted.

The required specifications of this system are given below.
- Applicable to various driving forms on public roads without divisional strips.
- Identifying and capturing the image of invalid vehicle are feasible.
- Collecting tolls from an IC card placed in an OBE is feasible.
- Applicable to all vehicles including motorcycles.
- Maximum vehicle speed for toll collection: 120 km/h
- Invalid vehicle detecting speed: 180 km/h
- Transaction error rate: 10^-4 or less
- Accuracy of vehicle separation: 250 mm (all around of the vehicle)

5.2.2 Test results

This trial system was tested by using a total of 8 000 vehicles from May to July 1995. The principal results are shown below, and they were found to satisfy all of the customer's specifications, described in each parentheses.
• Accuracy of toll collection: 100% (customer’s specification: error rate $10^{-4}$ or less)
• Detection rate of invalid vehicles: 100% (customer’s specification: 99% or more)
• Recognition rate of license plate number: 97% (customer’s specification: 95% or more)

Furthermore, in the system evaluation tests conducted in 1997, the conformity with the customer’s specifications was successfully verified by using more than 1 million vehicles in total.

6. Conclusions

The demand for the electronic toll collection system on tollways and the electronic road pricing system for traffic volume control in urban districts is expected to be on the increase in future. We obtained valuable know-how concerning future system developments by the experience in the development of the systems for Malaysia and Singapore. Henceforth, by making use of such experience, we shall continue to promote development of the new ETC system as a measure for solving environmental problems, seeking a greater contribution to society. As the standard relating to the ETC system, ISO/TC 204 has been established, and an attempt is being made to establish the standard for TICS (Transport Information and Control System) in it. In particular, WG 5 (AFC: Automatic Fee Collection), WG 1.3 (AVI: Automatic Vehicle Identification), and WG 15 (DSRC: Dedicated Short-Range Communication) of this ISO/TC 204 are closely related to the ETC, and MHI is planning to participate and cooperate in the development of equipment complying with the international standards.