Autonomous Driving Initiatives for Sustainable Public Transportation

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1. Introduction

Japan, Hong Kong and Singapore in Asian region are struggling to secure a labor force in the railway industry due to an aging society with a declining birthrate and a dwindling working age population. Train drivers in particular require high-level skills and experience, which is heightening needs for autonomous trains that do not require drivers due to the need for significant time for training to master those skills. Railway operators also saw profit drop during the COVID-19 pandemic. With future reforms to work and life styles, the demand for travel via railway may not return to the same levels as before the pandemic, which is further increasing the hope for autonomous driving from a management efficiency perspective.

Many urban railway systems have been adopting Communications-Based Train Control (CBTC) and self-driving trains overseas when constructing new lines as dedicated tracks with platform doors. Autonomous trains have found a foothold primarily in major Asian cities. Japan built the first automated driverless railway in the world on a commercial line of a new transport systems in the 1980s, which became the standard of autonomous trains. However, these self-driving trains did not immediately find traction due to the need for measures to prevent entry onto the tracks of existing railway systems with train crossings and no platform doors. Ongoing technical development and reviews of modifications to legislation are raising the potential for more widespread use in the future.

Since the first automated driverless train in the world began service on Japan's new transport systems, Mitsubishi Electric has been building a track record as the pioneer of driverless and autonomous technologies, promoting technical development that aims to realize as efficient and comfortable autonomous driving systems as possible.

This paper describes the framework for our autonomous driving, passenger service, and train service support solutions, which utilize the latest Mitsubishi Electric data processing and transmission as well as AI and sensor technologies, as a next-generation autonomous driving solution.

2. Three Solutions to Realize Sustainable Public Transportation

Urban railways must handle a high volume of passengers at each station in addition to staffing train drivers, conductors and other crew to ensure safe and reliable transportation, even when someone or something interferes with train crossings or the railway tracks. Mitsubishi Electric has analyzed the work done by crew in detail to realize automation that aims to reach a level higher than the new Grade of Automation Level 2.5 (GoA2.5: automatic-operation with a person for emergency stop operation. Japanese original definition) as a new standard of autonomous driving suitable to train services in Japan on standard railway lines with train crossings. These analyses have enabled us to advance the development of three automated driving solutions to systematize crew operations from driving tasks and decision-making to passenger services and troubleshooting.

(1) Autonomous driving solution

This solution mainly aims to automate controls used to drive the train. Drivers have to control the train, speed and continually make decisions taking into account various conditions that change moment to moment from passenger congestion and the status of the train to rain, snow, and other environmental conditions. We aim to realize a solution that provides ideal train services by autonomously determining each assigned role based on data collected from the network of onboard and wayside equipment.

(2) Passenger service solution

This solution mainly aims to automate passenger service systems. Train divers and conductors have an extremely important role and duty to keep passengers safe. For instance, the crew needs to respond to various foreseeable passenger scenarios that include passengers deboarding the train even after the departure time has passed or the high potential of door pinching of passengers as they rush onto the train. The use of Internet of Things (IoT), Artificial Intelligence (AI) and other cutting-edge technologies strives to not only maintain but improve on the passenger services currently provided by train crew.

(3) Service support solution

This solution mainly aims to automate tasks to troubleshoot problems on the train due to equipment failure or other abnormal situations. An autonomous train without any crew aboard that runs into trouble may suffer long delays until standard services resume while waiting for personnel to arrive to address the problem. Therefore, this type of solution must monitor the health of the train in real time based on data to deal with any problem that arises as quickly as possible before it disrupts train services.

The sections below describe case studies for these three solutions.

3. Autonomous Driving Solution

Autonomous driving systems have to replicate the necessary controls and tasks typically performed by train drivers and crew to realize truly autonomous train services. To optimize the control of a train, the solution has to collect data on a constantly changing railway environment in order to drive and control the speed of trains as well as make decisions based on various conditions that change from moment to moment, whether passenger congestion and the condition of the train or rain, snow and other weather conditions.

Mitsubishi Electric has amassed knowledge and expertise on train operation control system, train control and the wireless technologies that connect rolling stock with wayside equipment. We are also furthering the application of self-driving technology for automobiles propelling autonomous driving forward in applications for the railway industry. A solution would autonomously drive a train through sophisticated system links. Mitsubishi Electric is ramping up its efforts to realize that autonomous driving solution in order to successfully optimize train services through these links.

The following describes the mechanisms that configure the autonomous driving solution.

3.1 Control of trains through system links to wayside equipment

The major key to an ideal autonomous driving system that can automate the tasks typically done by drivers and crew is determining which system should handle each task.

Wayside Automatic Train Operation (ATO) equipment can not only simply notify each train of schedule data managed by train operation control system but can also broadly oversee the control operations and entire railway as fleets of trains. These capabilities can finely adjust arrival times to regulate the train headway or delay recovery operation. It is difficult for operators to make such adjustments manually.

Drivers perform delay recovery operation as necessary under their own discretion when any small departure delays occur due to opening and closing boarding doors multiple times. However, autonomous driven trains try to adhere to arrival times provided by wayside ATO systems by autonomously switching driving patterns between stations after the onboard ATO systems closes the passenger doors.

Figure 1 shows the division of these tasks. By assigning these tasks to respective systems, the solution can control services and save running energy of trains while considering all trains on the entire railway line.

Without a driver, railway operators do have concerns that autonomous driving will place a larger operation burden on operation control centers. However, the solution autonomously handles a majority of the operations done by drivers. This limits operation control center intervention to emergencies as is the case with current train services.

For instance, previously, the operation control center gathers information from the driver and passengers and give instructions to drivers when a disruption in service occurs. On a train using an autonomous drive system, the operation control center can give instructions to each train via a control console, control recovery of the train, and decide whether to continue autonomous operations based on the state of recovery. The control console even offers an ergonomic Graphical User Interface (GUI) that contributes to greater efficiency by enabling smoother operations.

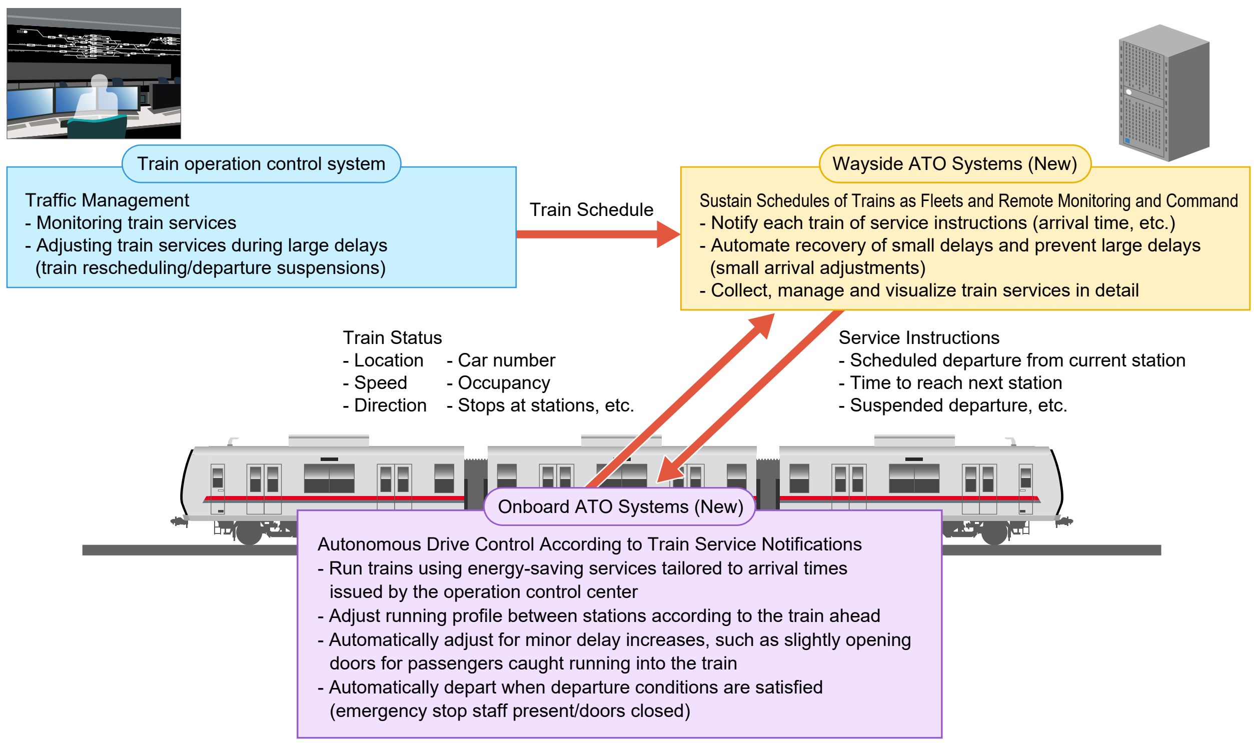


Fig. 1 Division of roles in the wayside-train interconnection system

3.2 Control as fleets of trains

A delay in one train due to a disruption in the schedule causes congestion as passengers wait for the train on the platform, which results in even further delays due to the extra time required for people to get on and off the train. To avoid such delays, the typical operation control center adjusts the train headway through wireless instructions. However, it is difficult for operation control center staff to adjust the large number of trains running on the entire railway line. The time required to recover schedule relies on the experience and expertise of the staff. Mitsubishi Electric is developing a train fleet control feature to overcome these challenges. This system wirelessly coordinates wayside and onboard ATO systems while optimizing and controlling the entire railway line to avoid station congestion and quickly get trains running on time again after delays.

Figure 2 and 3 present examples that quickly restore on-time train services by averaging the train headway. In both Figure 2 and 3, the top indicates verbal instructions for each train made by the operation control center while the bottom shows the new control system that handles trains as a fleet.

Figure 2 illustrates what happens right after departure delays due to higher passenger congestion when the station on the far left requires more time for passengers to get on and off the train. The typical and new control systems both have an equal train headway ahead at this point.

As shown in the top half of Fig. 3, typical instructions issued by the operation control center to adjust the train headway ahead after departure delays boards the increasing number of passengers at the station on the train ahead to mitigate congestion on the train that has been delayed. However, train headway expands when the train ahead does not receive the instructions that have to be issued to each train individually, which increases the amount of time it takes to average the train headway.

As illustrated in the bottom half of Fig. 3 though, the new control system can link the wayside and onboard systems to handle all of the trains as a fleet and adjust the departure times of all of the trains leaving stations. This process can quickly average train headway. We can expect this new system to more rapidly recover standard train services than typical instructions from the operation control center, which results in ongoing congestion. The new control system must issue commands according to the characteristics of each railway line. Train services that have trains overtaking one another need a well-balanced control that averages the train headway.

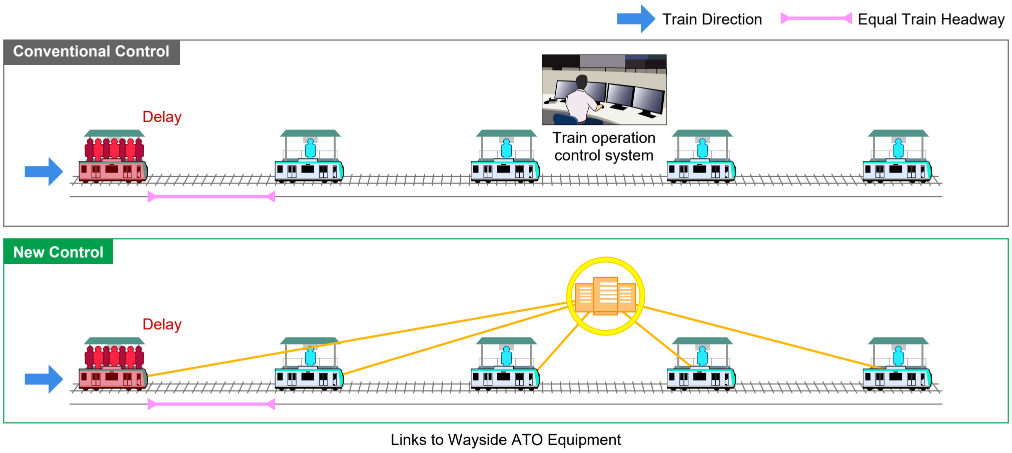


Fig. 2 Train position immediately after occurrence of delay

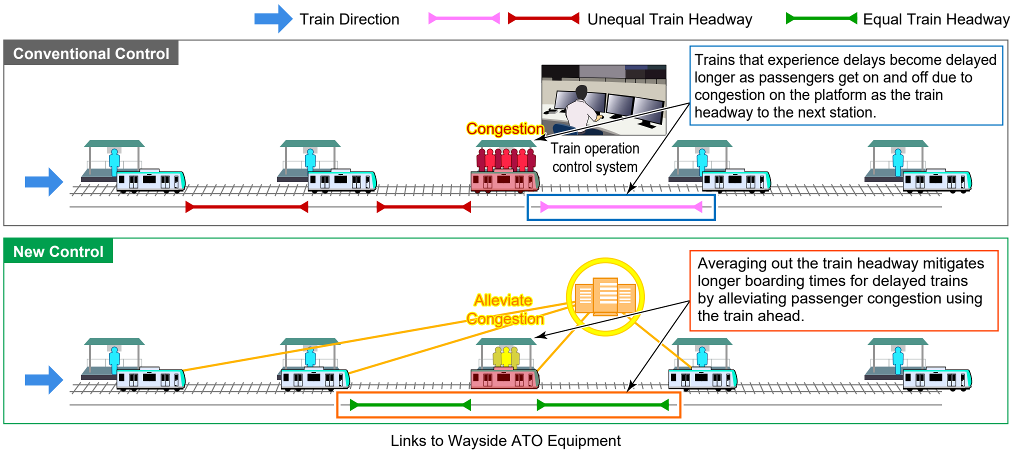


Fig. 3 Difference in congestion relief timing between conventional control and new control

3.3 Train crew monitoring

Self-driving vehicles in the automotive industry have led the development of control technologies that use various sensors, which has made drive control possible under specific conditions. Mitsubishi Electric is advancing a wide range of technological development, which includes its driver monitoring system.

We are pioneering new development for applications in the railway industry while capitalizing on our expertise in the automotive field. The following describes the driver monitoring system, which is one of these technologies. We are furthering development of this automotive driver monitoring system for railway applications as a crew monitoring system. This solution is intended for applications in autonomous trains equivalent to GoA2.5 that have conductor intervention, but it is also effective in automation at or below GoA2: semi-automatic operation.

The driver monitoring system developed for automotive use notifies drivers when a potential danger is detected from speed, steering and other vehicle data in addition to facial expressions, eye closure, head direction and eyeline.

The broader use of autonomous driving and one-person operations in the railway industry is increasing needs for railway operators in Japan to monitor driver health. A system installed in the train cab utilizes our expertise in the automotive field to monitor the health of drivers based on the unique railway environment and operational conditions as well as video data recorded by the onboard system. To prevent drivers from nodding off, the system measures eye closure as shown in Fig. 4 and uses time series processing to measure sleepiness. The system verbally communicates the measurements to the driver, issues driving instructions and notifies the driver's supervisor. Numerical values and video indicating the sleepiness of drivers helps the supervisors who oversee the driver and train services decide whether to switch drivers. The crew monitoring system also prevents excessive detection of sleepiness by linking the speed, location, direction, and other data about the status of trains received from the Train Control and Management System (TCMS).

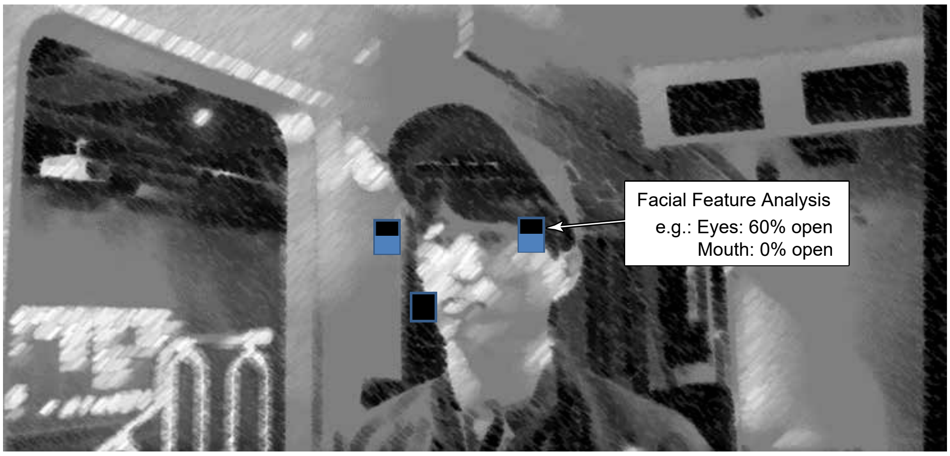


Fig. 4 Operating image of the crew condition monitoring system

4. Passenger Service Solution

Crew have primarily dealt with passenger services on trains up until now. The shift to autonomous trains requires the operation control center and systems to take over the services currently rendered by the train crew. However, this places a larger burden on the operation control center and makes it difficult to keep track of passengers and provide meticulous services with a limited crew.

Mitsubishi Electric automates these services by integrating leading-edge sensors, video analysis using AI, and wireless technologies with its train operation control system and control technologies. Services rendered collaboratively through the person in charge at the operation control center and system does not greatly increase work at operation control centers while sustaining safer and more compressive passenger services, even after the adoption of autonomous trains.

As one example of these wide-ranging initiatives, this section describes door-closing control AI.

Train crew are instrumental to train operations. Crew currently needs to have a high level of skill to open and close doors at the right time according to departure times and various other train service requirements in addition to controlling power and braking while considering passenger comfort to maintain regular train services.

Urban railway lines have a large number of people getting on and off trains. The crew needs to respond to various foreseeable passenger scenarios that include passengers getting on and off the train even after the departure time has passed or the high potential of door pinching of passengers as they rush onto the train. Train drivers must work to recover delayed train operations after a train departs late due to delays caused when having to open and close the doors. The proper automation of door opening and closing is an important initiative as departure delays lead to increased energy consumption.

Mitsubishi Electric is driving forward initiatives to automate door operations alongside the criteria to determine whether to close the doors considering the people getting on and off the trains, platform congestion, and other complex circumstances as well as link this to the train control system. Automation of tasks to determine whether to close the train doors involves AI analyses of video taken by ITV camera monitoring the platform typically used by conductors and drivers to decide whether to close train doors based on the location and circumstances around passengers.

As illustrated in Fig. 5, AI analyzes video from the ITV camera to integrate and assess the analysis results for each train to determine whether the train doors can close. This system automatically closes the doors by notifying the train of the analysis results wirelessly so that the onboard system can determine whether to close the doors while evaluating departure conditions from the departure time to data from the signal system. The unique Maisart AI technology provided by Mitsubishi Electric drives the efficiency of the AI analyses in this system to increase the speed of processes to determine whether to close train doors while responding to passengers running to rush onto the train and other sudden situations that arise. Through this approach, the system was able to make accurate decisions on when to close the train doors roughly 90% of the time in offline testing using ITV camera at several real stations.

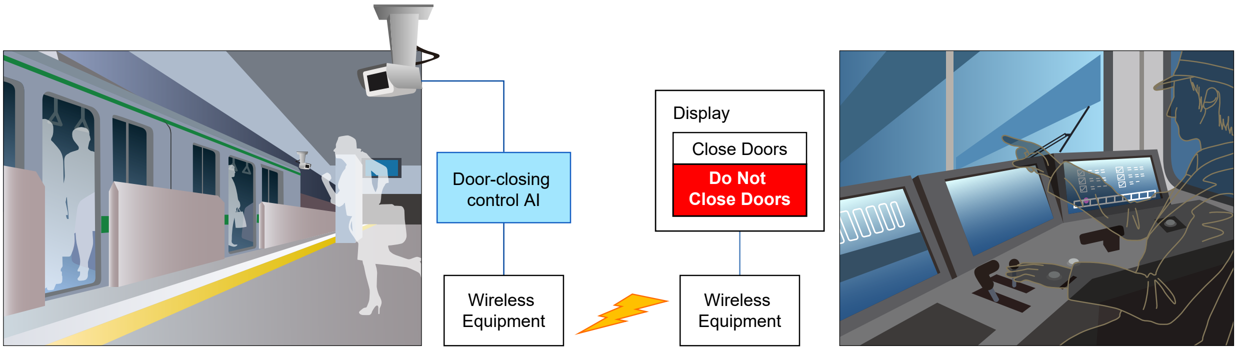
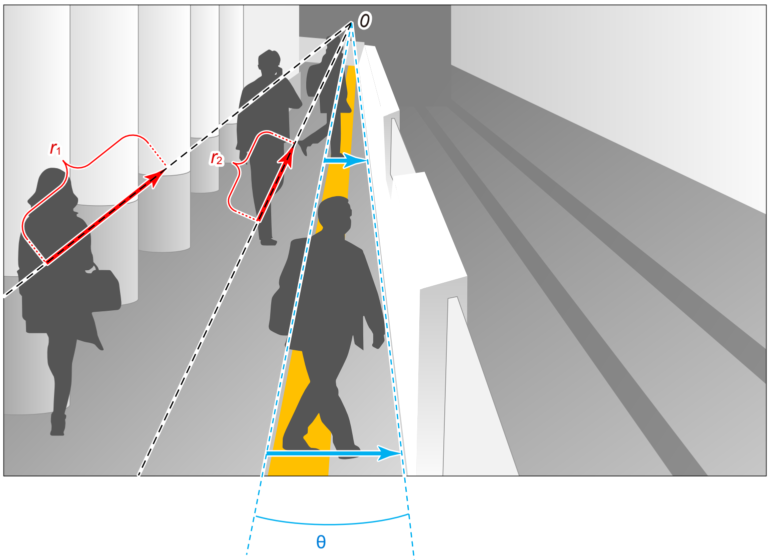


Fig. 5 Overview of the door-closing control AI

AI analyses has also struggled more to assess small figures far from ITV camera than those nearby. As shown in Fig. 6, development is advancing measures to implement motion extraction methods via coordinate transformations in order to overcome this challenge.

In the future, Mitsubishi Electric will further the efficient development of AI and evaluations in real train operations so that this system can easily accommodate multiple railways.



The system converts the platform into a coordinate system with the origin at the farthest end of the platform to determine the direction of movement using the theta component (length in the direction around the origin).

Fig. 6 Movement distance extraction method using coordinate transformation

5. Train Service Support Solution

Crew currently check the state of any trouble or other abnormalities on the train due to equipment failure while communicating with operation control center staff before the operation control center makes a final decision, and then issues instructions to reset equipment or shift to low-speed manual operations based on train service rules. On autonomous trains without any crew onboard though, remote operations limit tasks to recover standard train services, which is challenging because it requires a considerable amount of time to deploy capable crew to the site who can respond to the problem or drive the train in order to get the train up and running again.

Mitsubishi Electric is already building an analysis system that can track equipment degradation by collecting and monitoring operational data from each piece of onboard equipment via its unique INFOPRISM IoT platform to realize Condition Based Maintenance (CBM) that improves maintenance work. To further enhance functionality and establish a solution that can achieve stable train services, this analysis system has to assess the health of the train in real time based on data to more quickly vehicles exchange before failure or address any other potential problems. The solution would avoid vehicles exchange in operation that experience failures and lower the occurrence of service disruptions.

6. Conclusion

This paper has described the solutions that Mitsubishi Electric views as necessary for its autonomous driving system and some of the functions provided by those solutions. We are already working with railway operators to prove the concepts of these technologies while ramping up efforts toward practical use from data aggregation and problem detection to response analyses in the event of any abnormalities. In particular, safety evaluations are necessary and require proof-of-concept testing and third-party assessments. We recognize these efforts as priority initiatives.

Mitsubishi Electric is continuing to validate, review and collect data on the various solutions currently in development. We are doing everything in our power to provide solutions that both railway operators and passengers can feel secure in using sooner rather than later.

Railway operators made these proof-of-concept tests possible by providing a venue to validate each solution.

Mitsubishi Electric will continue to help maintain and expand sustainable urban and rural railway systems as well as other public transportation by strengthening relationships with railway operators and train manufacturers as well as representatives of various organizations and associations.

Reference

(1) Hoshiko, R., et al.: *Research on Door-closing Control AI Using Video Analysis and Deep Learning (J-RAIL2022)*; Conference Proceedings S4-1-1 (2022)