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An RFID-based Fallen Object Detection System: A Case Study of Hong Kong's Light Rail System

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Abstract **—Railways provide convenience and efficiency to the travelling public, with passengers' safety being the top priority in railway transit systems. Nowadays, with the population increase in many cities, railway safety and punctuality are of concern, and an effective surveillance system is needed to minimize the severity of an accident. The Fallen Object Detection (FOD) system is undoubtedly important in a surveillance system, as it is concerned with accidents that are due to objects falling through platform gaps. With the aid of advanced technology, Radio Frequency Identification (RFID) can be used for further enhancement in providing accurate and prompt information. An RFID-based FOD System (RFFODS) is proposed to ensure railway passengers' safety. A study of the RFFODS in a mass transit system is reported to illustrate the performance of RF technology for fallen object detection in outdoor environments. The location of an antenna is determined by using the Analytic Hierarchy Process. The feasibility and performance of the proposed system are verified with the results of an extensive on-site experiment conducted in a light rail vehicle station. It is expected that the proposed system would play a key role in establishing an intelligent monitoring system for passengers' safety in future railway developments.**

Index Terms **— RFID applications, Signal processing, Location, people and object tracking.**

1 Introduction

Due to the growing population, one of the major challenges in the transportation industry is to ensure safe performance. To design a sophisticated transportation system, other than on-time schedules and extensive travel routes, transportation environment surveillance needs to be taken into account for minimizing the accident rates and promoting railway safety. With the aid of advanced technologies, operation systems in the railway industry have been switching from manual operations to centralized automated control with human monitoring [1]. Although railway safety has been monitored, there are still many different causes of accidents. Dozens of passengers lose their lives every year when they fall from platform. From news articles, we can occasionally find out about various accidents when fall from platforms unintentionally or intentionally. A proper monitoring system is critical to ensure a safe operational environment with centralized control and the least human involvement.

Nowadays, many railway protection and supervision systems have been developed in different countries, such as Transmission Voice-Machine (TVM) deployed in France [2] and Automatic Train Protection (ATP) in Europe [3]. NDL Corp. (alias), a mass transit railway operation company based in Hong Kong, provides train, light rail and bus services to local communities. The Light Rail Vehicle (LRV) system has been operated for over 20 years, covering 68 stops across 36.15kms of track. In comparison with a train station, the platform in a light rail station is narrower, and may not be suitable for installing platform doors. LRVs are operated at the street level, sharing the space with road traffic. The gap between LRV and station is uncovered and even wide enough for three to four people to fall at the same time. Without any protection, passengers will fall more easily, especially visual impaired or disoriented people. Moreover, passengers and station staff are sources for notification of fallen-objects. Power and authority to handle the situation belong to the station regulator, but the station regulator may not be the first on the scene. A long lead-time and slow responsive action may occur due to complicated and duplicated processes. The current monitoring system in NDL Corp. uses an infrared (IR) beam installed under the front and back of the train compartment for detection. However, the system cannot operate steadily and detect properly under bad weather conditions. Concerning railway operation, safety and reliability are the utmost concern in aspects of an automatic detection system. Therefore, a highly accurate detection rate should be achieved, which means the probability of false alarms being generated should be minimized.

The aim of this research project is to undertake a comprehensive study of the design of an object detection system using Radio Frequency Identification (RFID) technology, on top of the currently applied technology systems. The main scope of this research project is to investigate the performance, in terms of accuracy and distinguishability, and response time, of the proposed RFID-based FOD system for outdoor application. Hence, Received Signal Strength Indicator (RSSI) is suggested to measure the effectiveness of the proposed FOD system. A case study is carried in NDL Corp., applied to a Light Rail Vehicle (LRV), on-site visits in the outdoor area of a depot, and off-site experiments are conducted for data collection. This paper illustrates the state of the art with regard to the usage of onboard surveillance technologies designed to address both safety and application issues in different countries, including a review of technology development in the railway environment.

2 Literature Review

2.1 Automatic Train Supervision

With advanced technologies, more comprehensive and real-time supervision systems have been developed consistent with train operation systems [4]. The Automatic Train Supervision (ATS) system is a governance system that makes strategic decisions by monitoring and recording the activities in traffic flow, routes, and schedule assignments. It aims to optimize service reliability and railway operations [5]. The unique feature provided by ATS system is the use of centralized computer-based supervision and control to process and exchange data with outside systems, make decisions, and formulate instructions for the entire line. Each component operation status on the train line is represented on the visualized panels, called Visual Control Panels (VSP) or Schematic Control Panels (SCP) [4]. The panel also provides a global view of the line operations and easy alarm visualization, and, thus, enables train drivers to concentrate on particular equipment during operation [1]. ATS systems are desirable for route planning and performance modification, when implemented with an Automatic Train Operation (ATO) system at the same time [6].

2.2 Trends in System Development

Today, outside of China, Japan, and the U.S., there are more than ten countries and cities that have high-speed railways [7]. Improving the safety and efficiency of the railway system is always of major concern, and there are three ways proposed by specialists to achieve this. Firstly, standardization of the train control system is needed, especially the physical and functional interfaces between stations and rail lines [8]. Secondly, hybrid and iterative learning control system approaches have attracted people's interest in recent years, and train control engineers are eager for new technologies or algorithms with cost-effectiveness and better integration performance [8]. The third way is developing autonomous systems with the aid of wireless communication systems, which can tackle the challenges in construction and control technologies.

2.3 Traffic Surveillance System

In order to deal with various complex security issues in railway operations, a wide range of surveillance and monitoring systems have been developed, such as the Driver Advisory System (DAS) [9]. The term "surveillance" implies vigilance, observation, and information gathering, and covers many forms of monitoring activities [10]. There are a number of reasons for installing surveillance systems. Firstly, it can ensure passenger and staff safety. A surveillance system functions in protecting employees through monitoring, solving passenger complaints, and providing risk management training support. Secondly, it can reduce fraudulent injury claims and mitigate liability and accident claims. Besides, surveillance recordings provide strong evidence, especially in criminal cases, and, hence, support risk management in identifying false or exaggerated claims [11]. Lastly, emergency support is provided in resolving incidents, such as automatic transmission of audio or image information to central control or security centers. Therefore, with an effective usage of surveillance systems, a surveillance system can bring benefits to not only the organization but also the public and the government.

2.4 Fallen Object Detection System

The Fallen Object Detection System (FODS) is a fault-state identification system used to detect possible obstacles on tracks or the areas where there is a high possibility of intrusion automatically [12]. The aim of using FODS is to prevent collision with obstacles, such as people and vehicles. In general, there are two primary sources of FODS. One is using mechanical sensors, while another is human observation. For both technical and human determination, detective and optical ranges are restricted. Multiple data need to be verified; however, the response time has to be sacrificed. The challenges in using detection systems are the detection time, classification, and identification of objects in real time [13]. In the article written by Gandhi et al. [14], detection may fail if the objects are relatively small in volume and mass, if there are numbers of clutter disturbances in the region of interest, or if there are environment factors. Nowadays, many technologies have been enforced in real-life operations, such as artificial vision, IR sensors, and microwaves. Meteorological conditions are a major factor affecting the performance of these technologies. To perform the detection of fallen objects, there is a wide range of technologies that can be applied, namely ultrasonic sensors, IR, Video Image Processing (VIP), and Radio Frequency Identification (RFID). In the following portions of text, the technologies chosen in this research project are reviewed and described.

2.4.1. Ultrasonic Sensor

Ultrasonic sounds are sound waves above the normal range of human hearing (i.e., greater than 20k Hertz) and is transmitted through the propagation of pressure in air. Typically, a digital signal processor embedded in the sensor calculates the distance between the sensor and an object. Initially, ultrasonic sensors were rarely applied in the outdoor environment due to the unique mechanisms of acoustic wave propagation, such as atmospheric refraction, absorption, and turbulence, and it leads to extra attenuation on the transmitted signal used for the standard calculation method. In 2004, a study conducted by Alvarez and other colleagues, an ultrasonic sensors system for falling object detection on the railway was proposed for an outdoor application [12]. It used signal coding and processing based on the use of complementary sequences, which can minimize the effect of atmospheric turbulence and allow a stable system against the fluctuating amplitude of the signals. The main characteristics of the proposed system are that the system can adapt itself to a situation where significant attenuation of the ultrasonic waves occur, and there is no mistaking temporary losses of energy for recognizing a falling object due to insensitivity. This arrangement enhances the robustness of the system to detect any static obstacles under different atmospheric turbulence conditions [15]. This system is estimated to have a detection period of 164 ms, and it performs particularly well under weak turbulence conditions, such as foggy atmosphere. It also works well in condensing moisture, can detect most materials, and ignores background objects. However, it requires a minimum surface area for detection, works poorly in sound absorbing material, and has a slower response time than other technologies, of about 0.1 second.

2.4.2. Infrared Sensor

IR is a technology in which a narrow-band IR beam is reflected by the target, and the reflected light is received in the allocated sensors. It is regarded as a more extended wavelength portion compared with visible light and radio waves [10]. The distance between a sensor and the reflecting object is used for determining the incident angle of the reflected beam. An IR system contains pairs of emitters and receivers for locating each other at different sides on a straight line. There are two types of IR sensors: one is an active sensor, which emits the same wavelength to objects for distance measurement and motion detection, and the other is a passive sensor, which is used for detection of the temperature and thermal radiation. The farther away the reflecting object is, the slighter the angle. IR detectors have been widely used due to their simple and easy implementation with few components needed. They are commonly used for motion sensors, such as open doors, monitoring gateway traffic, turning on lights, and detecting intruders [16]. Additionally, an IR sensor can be operated both day and night. However, the performance of IR sensors is profoundly affected by its poor tolerance to light reflections (i.e. ambient light) and in a critical environment (i.e. rainy) [17]. Besides, due to the limited analysis for analog signals at 1 and 0, the blocking of the IR beam can only detect the presence of an object but not the position of it on the detection line. Hence, the detection of a typical situation with a fallen object is the same as the rainy situation with no fallen object. Also, most IR sensors need to be lined up, so the detection area for operation is limited. Therefore, the choice of materials detection, the complexity of system construction, and signal processing algorithms are limited. The most critical problem is the IR sensor that may easily pickup noise detection.

2.4.3. Video Image Processor

Nowadays, video cameras have become popular in the application of object-detection surveillance systems. Cameras are installed along the vehicles or on the edges of platforms to obtain the maximum range of visibility. Originally, Closed-Circuit Television (CCTV) was widely used for railway surveillance. However, CCTV systems require manual continuous monitoring of the video images, which is a passive system, so that no immediate recognition or response capability can be given in an emergency situation. As a result, VIP has been developed. It is a combination of hardware and software which generates processed information by using vision sensors. There are some algorithms, such as the online-boosting algorithm [18], that can be integrated for tracking and detection. By using stereo image processing, the influence of shadows and reflected lights over the surroundings can be easily eliminated, which is difficult in mono-camera image processing [19]. The successful detection of an Object of Interest (OOI) depends on the availability of any foreground objects and the complexity of the background scene. There are a number of approaches that have been developed for tackling foreground object extraction and detection in a very crowded scene, such as that developed by Rodriguez, et al. which uses an algorithm for tracking in unstructured scenes [16]. Using camera systems not only enables recording the images, but they can also trace, detect, and predict action through the images. Hence, it can provide both raw and analyzed data such that the distance, speed, and height of the objects can be measured by using a stereo camera to differentiate from a small object [20]. Since there is no need for manual monitoring, a camera-based system can increase the effectiveness of the monitoring [21]. In addition, high flexibility in the detection zones can be achieved by simply changing the viewpoints of the cameras. However, the performance of surveillance cameras will be affected by any solid and reflective materials, such as shadows, reflection objects, walls, leaves, and vapor [21]. Each of these will hinder the image transmission to the receivers. There is no problem in object detection in most cases, but detection in the nighttime and objects with protective coloring against the background will lower the detective power of using VIP.

2.4.4. Radio Frequency Identification

RFID is an Automated Data Collection (ADC) technology, which refers to the wireless usage of Radio Frequency (RF) waves to transfer data between a reader and an object with a tag attached. RFID applications have been widely adopted in logistics and supply chain management, such as shipping and port operations, resource allocation systems [22], inventory management [23], storage object orientation detection [24], real-time locating systems [25], object tracking [26], and object locators for finding misplaced household or personal objects in an indoor environment [27]. A typical RFID system contains several components: transponder (i.e. RFID tags), antenna, transceiver (i.e. readers), and middleware (i.e. computer system). The data is recorded by radio signals emitted from the reader and is then transmitted to a computer system for further processing. Simultaneously, the continuous data processing and signal transmission allow the reader to track the location and movement of the tag in real time.

An RFID tag consists of a chip (i.e. a silicon integrated circuit), which transforms the received electromagnetic fields into an electronic signal for its use, and, with its unique identification (ID) embedded, then sends it back to the reader. RFID tags can be attached to almost everything, such as pallets, vehicles, or even human beings. There are two types of tag communication methodologies, namely "active" and "passive". In general, active tags allow lower power use for the RF, support longer communication distances, and larger memories than passive tags, but the cost is higher than that of passive tags. To perform communication and data processing, RFID tags and the reader must use the same working frequency and comply with specific protocols for compatibility. By using the antenna, RF signals can be transmitted from a reader to the surroundings and can then be collected from the tag responses. Therefore, the location of the antenna is more important than that of readers, with high accuracy and response rate. To perform communication and data processing, RFID tags and the reader must use the same working frequency and comply with specific protocols for compatibility. There is no theory of "one frequency fits all applications". The higher the frequency range, the higher the power, bandwidth, cost, and needs of line of sight, and the lower the lifespan and detection range.

Received Signal Strength (RSS) is one of the basic properties of a radio signal [28], and it is compatible with a wireless communication system with minimal or no hardware changes. RSSI is a physical parameter obtained via an RFID system. A signal propagation model is used to accurately describe the relationship between the Antenna-Tag distance and the RSSI values [29]. The higher the RSSI values, the stronger the RF signals. It can be used to locate [30], track, and identify [31] objects within the navigation areas [32]. Some common materials can affect the strength of the radio waves, which can be classified into three categories: RF-lucent, RF-opaque, and RF-absorbent [33]. In applications, cardboard absorbs RF waves due to moisture while human beings also have various effects (i.e. reflection, absorption, and detuning) on the RF waves.

2.5 Summary

After reviewing several topics in railway systems, it can be concluded that automatic control systems are inevitable in existing and future train operations, especially in the application of surveillance systems. In the current railway industry, there are already wide ranges of automatic train operation systems for controlling and monitoring. Additionally, various papers have already studied different technologies in the areas of detection, locating, tracking, and communication. Considering the rapid response ability and monitoring area, RFID technology is an outstanding technology providing more object classification possibility in a narrow outdoor environment. Indeed, there is a lack of research focusing on the area of using RFID technologies for fallen object detection systems in railway operation. It is found that radio waves are rarely used in outdoor areas, so RFID technology is seldom used for FOD systems. Thus, a study was conducted for using RFID for fallen object detection in an outdoor environment.

3 METHODOLOGY

An RFID-based Fallen Object Detection System (RFFODS) was designed and built to maximize the detection areas and accuracy. RFFODS is used to detect any fallen passengers or objects between the train and the platform. The concept of RSSI is to collect the changes in RF power strength, which allows systems and operation staff to recognize signal differences, distinguish the causes of interference, and perform corresponding emergency approaches promptly. The objectives were to design system components for facilitating the implementation of the proposed system in the transportation context, to demonstrate the feasibility of the RFID-based FOD approach as a proof of concept in current studies, and to develop an FOD system prototype to support an automatic train control system and minimize false alarms. A reference site of the railway in Hong Kong was selected for trial implementation to illustrate the application of the system. Trial implementation results were used for performance verification. RFFODS was proposed for the functions, operation, and information flow. The prototype of the system was then built. A simulation experiment was performed to study the feasibility of RFID-based moving object detection. Several discrete or continuous input variables were varied, controlled, and tested in each experiment. After that, an on-site experiment applying RFFODS was carried out in a selected reference platform in Hong Kong. The results from the off-site and on-site tests were evaluated by using different statistical methods, including T-Test and Analysis of Variance (ANOVA). System design parameters were determined by comparing different design configurations.

3.1 Design Requirement

Various design requirements were important for compatibility of RFFODS implementation and further support in efficient train surveillance. Firstly, the train must be equipped with at least ATP and ATO systems, or even ATS, because it enables the processed data transmission from the RFID detection input devices to the control system. Secondly, the organization needs to ensure the current information system can integrate, capture, and process real-time data by using RFID hardware, software, and other related devices. It is vital that the information system can handle, aggregate, and present the processed data in such a way to support strategic decision formulation and control.

3.2 Architecture of RFFODS

To demonstrate train operation management dealing with fallen objects in a network approach, RFFODS consists of three key divisions in the view of operating integration: signal transmission, data processing, and contingency response. The fundamentals of the system are supported by data capturing and processing using RFID technology. The RSSI value obtained by the antenna installed on the train would input to the system. RFFODS monitors the railway environment continuously by computing the RSSI value. In case some objects fall onto the track, RFFODS will automatically detect them and compare RSSI values changes against the acceptable range of the RSSI value. If the collected RSSI values exceed the range, the value will be transmitted to the integrated information system to process and record. An alarm will then be generated to the train operator's cab and station control to alert the fallen object detection. Station staff can then contact relevant units (i.e. paramedic and security guard) while the train operator can make an announcement via microphone to alert passengers in the compartments. Through the information system, ATO and ATP can perform automatic speed control and stop the train for safety. The RFFODS annunciates "detected fallen objects" within a second when a passenger falls onto the track from the platform. Figure 1 shows the operation process of RFFODS.

3.3 System Verification

To evaluate and verify the methodology of the RFFODS system, a prototype of RFFODS was established by conducting off-site and on-site experiments. In all off-site and on-site experiments, 300 units of data were collected for each scenario with 30 repetitions. The experiments were aimed at identifying tag positions regarding readability and applied technology performance in response time and variability of the RSSI values. For the experiments, Tag Orientation Analysis (TOA) was applied for testing the best location and orientation of the tags. After determination of the tag positions, some statistical methods, such as T-Test [34, 35] and ANOVA, were used to evaluate the collected RSSI data for obstacle detection feasibility. The T-Test is used to assess whether the means of two samples are statistically different from each other, and ANOVA measures two sources of variation in the data and compares their relative sizes (i.e. variation between groups). There were two types of variables used and measured in the experiment. One was the dependent variable, which represented the output data variation between experiments, including response time, RSSI values, number of responses, humidity, temperature, obstacle distances, and experimental duration. The other was the independent variable, which referred to the input variables fixed in the experiment, including antenna location, height, horizontal angle, vertical angle and orientation, types, and height of tags, dimensions of the platform gap, and the distance between tags and the antenna.

3.3.1. Antenna Placement

In order to minimize the dependent variables, the Analytic Hierarchy Process (AHP) was applied for determination of the antenna locations. AHP has been developed since the 1970s for resource allocation for military use [29] and is a common tool in multiple-criteria decision-making [30]. AHP can be used as a hierarchical representation of a system, containing several levels of attributes and sub-attributes [36]. It is a process for developing a numerical score to rank each decision alternative based on how well each alternative meets the decision maker's criteria [37]. The procedures of AHP involve several essential steps:

Step 1: Defining goals and structuring the hierarchy of the decisions (criteria, detailed criteria and alternatives).

Before starting the calculation, all goals and criteria needed to be identified. The graphical representation of the hierarchy is shown in Fig. 2. There were three locations considered in the compari-

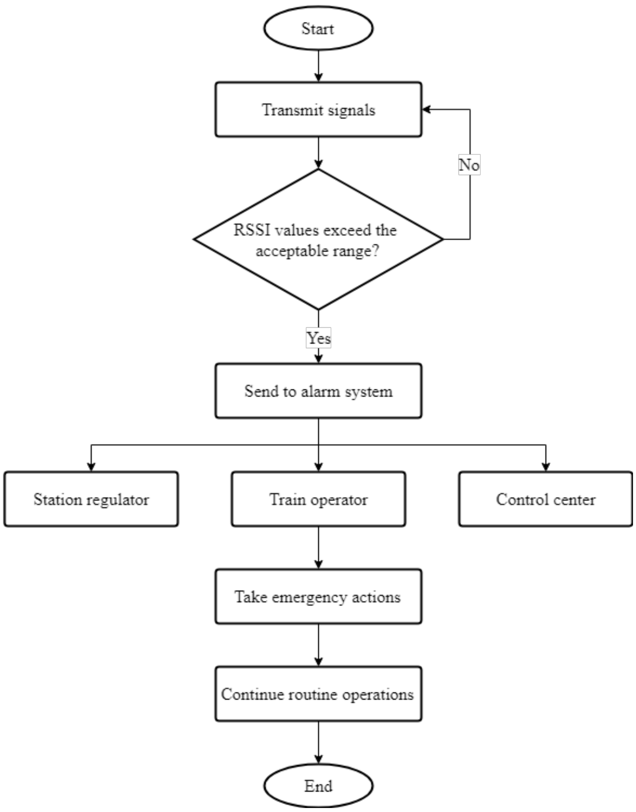


Fig. 1. Operation process of RFFODS.

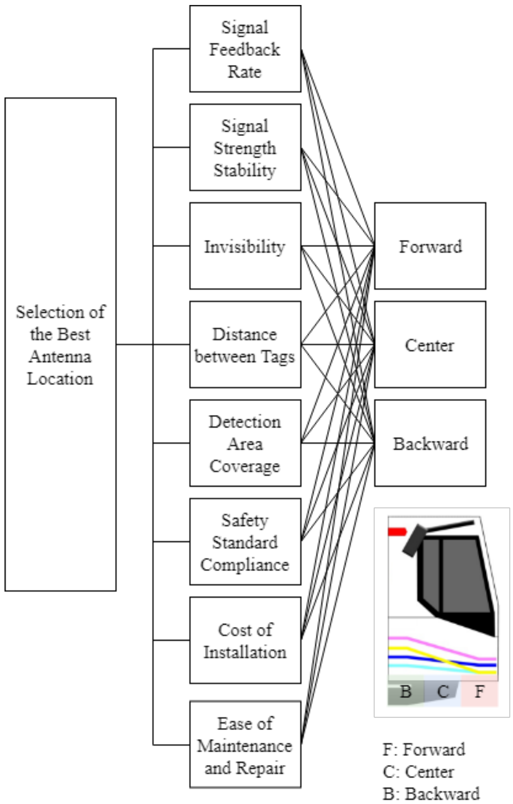


Fig. 2. AHP hierarchical structure for antenna placement design criteria.

son: forward, backward, and center of the underframe of the train compartment. In order to implement the object detection system successfully, the experts defined several issues to be considered:

(i) *Signal Feedback Rate:* This criterion defines the stability of detection performance every second.
(ii) *Signal Strength Stability:* This criterion defines that the RSSI values stay within a proper range.
(iii) *Invisibility:* The possibility of system component exposure that could damage or influence the normal system operation.
(iv) *Detection Area Coverage:* In order to have maximized governance area, the detection system should cover the maximal allowable area.
(v) *Safety Standard Compliance:* The antenna location will not hinder the railway operations.
(vi) *Cost of Installation:* The cost criterion involves the total amount of the first investment and component installation costs.
(vii) *Ease of Maintenance and Repair:* The system should be installed regarding the degree of convenience in checking and maintenance.

Step 2: Establishing a pairwise comparison matrix for selection criteria.

AHP employs an underlying scale with values from 1 to 9 to rate the relative preferences for two items. For every attribute C_{ij} of the matrix, the measure of preference of the item in a row *i* is compared to the item in a column *j*; the reciprocal (inverse) value of C_{ij} is used to obtain the preference rating of C_{ij}. The details of the nine-point scale of measurement are listed in Table 1.

Step 3: Collecting data from the selection panels.

Through direct questioning, experts who are experienced in RFID-based system implementation for more than five years are interviewed for obtaining data. A questionnaire is designed to collect data that determines the weights of attributes in the decision hierarchy.

Step 4: Employing pairwise comparisons and estimating the relative weights of attributes.

All attributes need to be compared with the priority scale, pair-by-pair, so that a paired matrix is formed. After the pairwise comparison matrix is developed, a priority vector is calculated and is then normalized to sum to 100%.

Step 5: Calculating the degree of consistency in order to validate the results.

In order to assure the validation of the rating, the Consistency Ratio (CR) is calculated for measuring the consistency. If CR is equal to or below an acceptable range, then the weight results are valid. In this case, CR is 9.347%, which is below 10% for the first level of hierarchy, with 9.609%, 4.773%, and 8.338% for the factors "Safety Standard Compliance", "Detection Area Coverage", and "Signal Strength Stability", respectively. Therefore, the weight results are valid.

Step 6: Calculating the relative weights of those ratings with acceptable degrees of consistency for the selection criteria.

The overall weight is just the normalization of the linear combination of product of weight and priority vector.

After having the pairwise comparison assessment, the results of the pairwise evaluation of attributes and the combination of priority weights are given in Table 2. The composite weights are the ratio scale. It was concluded that the antenna placement should be at the back of the underframe of the train compartment, which was 2.18 times more preferable than placing forward, and placing it in an underframe backward location was 4.25 times more preferable than placing in the center of a train underframe. The results of the three alternative normalizations show the recommended position of the antenna placement, which was the underframe back edge of the train compartment.

TABLE 1
Saaty's scale of measurement in pair-wise comparison

Rating (Intensity of Importance)	Definition	Description
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance	Experience and judgement slightly favor one over another
5	Strong importance	Experience and judgement strongly favor one over another
7	Very strong importance	An activity is strongly favored and its dominance is demonstrated in practice
9	Absolute importance	The importance of one over another affirmed on the highest possible order
2, 4, 6, 8	Intermediate values	Used to represent compromise between the priorities listed above

TABLE 2
Weight of criteria and alternative antenna location

Criteria	Weight	Priority	Alternative Antenna Location	Weight	Priority
Signal feedback rate	0.0922	4	Backward	0.5909	1
Signal strength	0.1836	3	Center	0.1389	3
Stability invisibility	0.0717	5	Forward	0.2701	2
Detection area coverage	0.2231	2			
Safety standard compliance	0.3552	1			
Cost of installation	0.0496	6			
Ease of maintenance and repair	0.0246	7			

Therefore, the antenna was fixed to the edge, as shown in Fig. 3.

3.3.2. Tag Orientation

For the tag orientation, experiments were conducted according to the actual layout of the platform gap, and the proposed location of antenna and tag positions as shown in Fig. 3. For increasing the RSSI value creditability and system validation, two tags were used for the final on-site experiment and can be located at two places with four orientations, as shown in Fig. 4. By considering the dimensions of a platform gap for an LRV, a tag could be placed in the forefront position at 2.55 m from the edge point A of the gap, and the last position point for placement was 4.3 m from the edge point A of the gap. The maximum read distance of using the Alien RFID kit set is 0.5 m, while that of using the Harting RFID system is 1 m. Therefore, signal strength data was collected and recorded in every 0.5 m using the Alien RFID kit set, but in every 1 m using the Harting RFID system.

3.3.3. Hardware and Software Selection

For the software selection, there were two commercial brands of RFID kit sets for testing. One was Alien RFID Gateway (Set A), another was Harting RFID system (Set B). Software attached with their RFID Developer Kit was used for evaluating the most appropriate tag orientation and position. In this case, the read zone was at most 4.3 m long, and tag sensitivity as not a critical parameter. The comparisons of readers and antennas are shown in Table 3, and the comparisons of tags are shown in Table 4.

3.3.4. Data Measurement

Implementation of the RFID system focused on the optimization of each system design. The optimization of the RFID system included identification of the location, placement, and orientation of the antenna, tag, reader, and other related devices. Hoong [31] and Ammu, et al. [32] showed significant results in the collected data by optimization. The main measurement of the system was the number of collected data for every scenario experiment and its repetition. In order to objectify the experiment results, TOA, T-Test, and ANOVA statistical methods were used to analyze and evaluate the efficiency [31].

4 Case Study

NDL Corp. is a leading rapid transit railway system in Hong Kong and was established in 1975. Until 2014, it was estimated that there were nearly 4.47 million passengers per day. With the aid of advanced technologies, developing an automotive detection system with accurate signaling and fast response is necessary to enhance transportation services further, especially for outdoor operations with variables of weather and environmental noise. The LRV system in Hong Kong, which has not retrofitted any doors or gates on a platform of deports, was used for investigation and implementation for a case study in this research project. Comparing with different light sources, e.g. sunlight, incandescent lights, LED, and fluorescent lights,

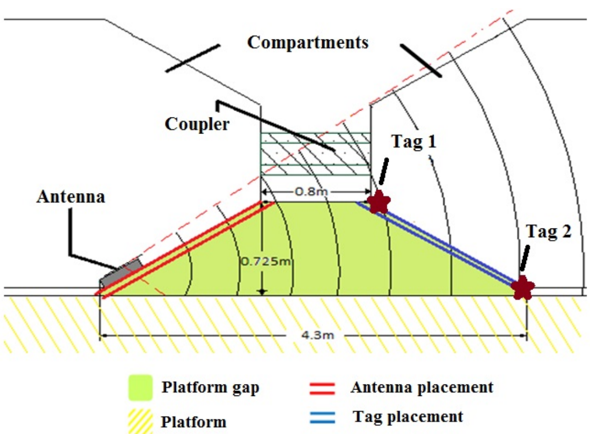


Fig. 3. Actual configuration of platform gap.

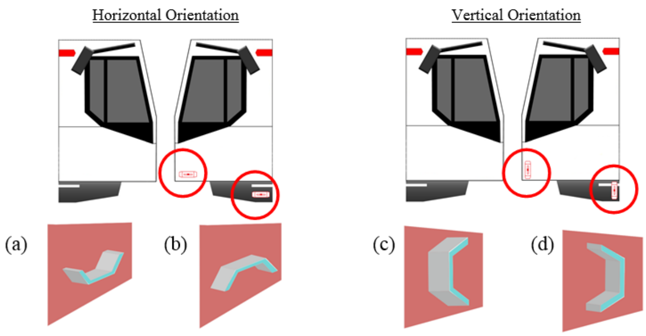


Fig. 4. Combinations of tag placements.

TABLE 3
Basic comparisons of the readers and antennas

Attributes	Brands			
	Alien (set A)		*Harting (set B)*	
	Reader	*Antenna*	*Reader*	*Antenna*
Model	ALR 9900	ALR 9610	RF-R5000	RF-ANT-WR30-EU
Polarization	-	Circular	-	Circular
Frequency	920-925 MHz	865-960 MHz	860-960 MHz	865-870 MHz
Protocol	IP53	IP54	IP64	IP65
VSWR	-	1.5 : 1	-	<1.2 : 1
Gain	-	5.73 dBi	-	8.5 dBi
Environmental rating	Ease of use and cost saving in protocols	Thin and light weight	Applicable in metal-rich environments	With aperture angle of 70°, range up to 10m.
Temperature	-20°C to +50°C	0°C to +50°C	-25°C to 50°C	-20°C to +55°C

TABLE 4
Basic comparisons of the RFID tags

Attributes	Brands	
	Alien (set A)	*Harting (set B)*
Model	ALL-9440-02	Ha-VIS RFID SL 89 Set V1
Size	98.2 x 12.3 mm	320 x 60 x 50 mm
Frequency	860-960 MHz	860-930 MHz
Merits	Good for packaging including products containing metals and water	Suitable for both metallic or nonmetallic surfaces, with more than 10m read range
Protocol	EPC Class 1 Gen 2	EPC Class 1 Gen 2
Chip	Alien Higgs 2	Alien Higgs 3
Memory	240 Bits	512 Bits
Temperature	-25°C to + 65°C	-50°C to + 85°C

only fluorescent light affects an RFID system in close proximity [38, 39]. Fluorescent lights reflect RF waves causing "null zones" at UHF and higher bands. It becomes a greater problem the closer they are to the RFID system or a tagged object. A practical solution for the fluorescent lights could be to move or replace with them LED or incandescent lighting, if possible, or using RF-absorbing materials, such as carbon-loaded foam, between the fluorescent lights and the RFID system. In our case, fluorescent light in LRV stations were far from our proposed RFID system and brought no significant effect on the proposed system.

4.1 Off-site Experimental Testing

For the tag placement and orientation, the tags can be located at two places and can be changed to four orientations, as shown in Fig. 4. Obstacles testing mainly focused within the platform gap area highlighted in green in Fig. 3. Each scenario was repeated 51 times, while the first one was treated as a feasibility trail and then data was recorded the remaining 50 times. Since the analysis focused on the average RSSI value, the value of outliers were excluded for prudent calculation, which is given by

$$\text{Average value} = \frac{\text{Sum of data value} - \text{Maximum value} - \text{Minimum value}}{\text{Number of times data collected} - 2}. \quad (1)$$

4.2 On-site Experiment

In general, the same scenario setting in off-site experiments were conducted in the on-site experiments, but external factors were taken into account. Different kinds of independent variables, including the height of the mounted tags and antenna and the distances between them, temperature, humidity, position of the obstacle fallen, and so on were taken into consideration. A thermometer and a hygrometer were also used for data records. Experiments were conducted by varying the scenario factors, such as obstacles and rain.

5 Findings and Discussion

Based on the methodologies, both off-site and on-site experiments were required for an efficient and effective research procedure. Through the off-site experiments, the analysis focused on the preliminary setting design of the experiments, and was the basic setting for the on-site experiments. In the on-site experiments, the analysis focused on the detection ability of the research project objective and the feasibility for practical operation.

5.1 Simulated Off-Site Studies (Experimental Testing Comparions)

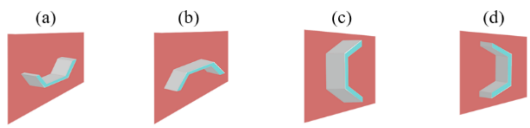
After conducting off-site experiments between different distance points, the average RSSI values obtained using Set A is shown in the Table 5, and data obtained using Set B is shown in the Table 6.

For Alien setting, it was found that the overall signal strength of using orientation (d) is the highest and strongest. However, the proportion relationship between the increase of distance point and the RSSI values does not show any stable changes. For the reading stability, Standard Deviations (SD) between different orientations were used for comparisons. Averages of the RSSI values obtained at each distance were used for calculation of SD in different orientations. The orientation with the lowest SD value is orientation (d), which is 0.34 decibel-mill watts (dBm). It can be concluded that the variation of the RSSI value is minimum by using orientation (d), which means the signal strength is also more stable than the other orientations. By comparing with the collected data and experimental results of using Set A, the results of using Set B show the same performance of tag placement and orientation so that orientation (d) had the strongest signal strength and stability with the lowest SD value. The only difference between Sets A and B was that the RSSI value was changed to a negative value in Set B, and the changes were not significant between distance points.

Other than the tag placement location and orientation testing, the detection ability was also determined. A volunteer was used for obstacle detection testing. For the detection ability testing, continuous reading within 30 seconds was conducted, while the object would fall into the gap area after 10 seconds and would be moved off after 20 seconds. A single tag was placed at the distance point of 4.3 m in order to find the best result for the farthest distance of the tag placement. For Set A, it was found that the normal RSSI value without any obstacles was mostly within the range of 28 dBm to 30 dBm, while the RSSI value with obstacle detection was mostly within the range of 26

TABLE 5
The RSSI value in different distance points and orientations by using the set A (Alien devices)

Distance Point	Horizontal Orientation		Vertical Orientation	
2.55 m	(a) 28.5,	(b) 29.1	(c) 28.8,	(d) 29.8
3 m	(a) 28.4,	(b) 28.8	(c) 28.5,	(d) 29.6
3.5 m	(a) 28.0,	(b) 28.6	(c) 28.4,	(d) 29.5
4.3 m	(a) 27.2,	(b) 28.1	(c) 27.8	(d) 29.0

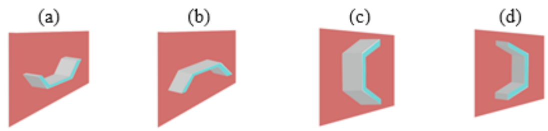


SD = 0.59 dBm SD = 0.42 dBm SD = 0.42 dBm SD = 0.34 dBm

SD = Standard Deviation

TABLE 6
The RSSI value in different distance points and orientations by using the set B (Harting devices)

Distance Point	Horizontal Orientation		Vertical Orientation	
2.55 m	(a) -58,	(b) -56	(c) -57,	(d) -56
3.5 m	(a) -63,	(b) -61	(c) -60,	(d) -60
4.3 m	(a) -67,	(b) -66	(c) -65,	(d) -62



SD = 4.5 dBm SD = 5.0 dBm SD =4.0 dBm SD =3.1 dBm

SD = Standard Deviation

dBm to 29 dBm. Set B was more sensitive to an instant drop of RSSI values when blocked by an obstacle, and the RSSI value in a "clear field" was relatively more stable than that of the Alien setting. It provided a competitive advantage in making fallen accident alerts. It can be concluded that the overall performance of obstacle detection using both systems are satisfactory, and further system development is possible for obstacle location determination.

5.2 Practical On-site Studies

In the below section, result discussion of Set A is excluded because no RF wave from either tag was detected when an obstacle existed in the on-site environment. Although Set A had been proven in the indoor area during off-site studies, this detection problem was found in the case scenario. In the perspective of a train operator, he or she could not determine a reason for a signal to not be detected. Hence, in view of system stability, Set B was chosen only for the on-site studies.

5.2.1. Finding Acceptable RSSI Value Range for Object Detection

Other than only comparing with the mean and checking the ability for detecting an obstacle, it was necessary to find the acceptable range of the RSSI values with no obstacle. The RSSI values vary for several reasons, such as air moisture and temperature. Other than using a single RSSI value, an acceptable range of the RSSI value should be calculated. If the RSSI value was outside the acceptable range, an alert would be given for the obstacle detected. The maximum and minimum RSSI values were used to calculate the average RSSI value at different distances to find out the percentage change in normal situations. According to the off-site experiments, two tags were used and placed 2.55 m and 4.30m from the antenna. Figure 5 shows the RSSI values obtained at 2.55 m and 4.30 m from the antenna in normal situations. The signal strength for both tags received was almost the same with the RSSI value changes; the minimum acceptable range was above or below the mean of the RSSI value of around 9.0%.

For on-site experiment data, the same concept was applied in that the RSSI value should not exceed the average RSSI value, more or less than around 9.0%. Figure 6 shows the RSSI values collected in the on-site experiments in non-raining conditions. For Tag 1, colored in blue, the acceptable range of the RSSI values was between -53 to -63 dBm, while the acceptable range for Tag 2, colored red, was between -51 to -61 dBm. Under normal situations, the acceptable range should fit within the 9.0% variation. On the right-hand side of Fig. 6, it shows that when there was an obstacle falling into the platform gap, the RSSI value decreased and exceeded the acceptable level, which means below -63 dBm. Both tags have a decrease in the RSSI value of more than 9.0%, with a response time of nearly 1 second. Both tags had a decrease and exceeded the acceptable range of the RSSI value, and, thus, it is feasible to generate messages and analyze data in the alarm system.

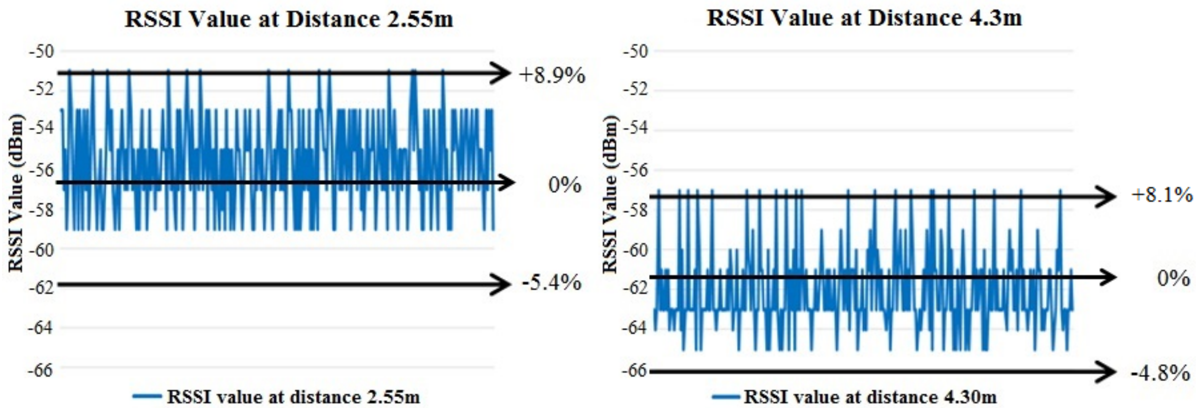


Fig. 5. Comparison of off-site experiments on the RSSI values at 2.55m.

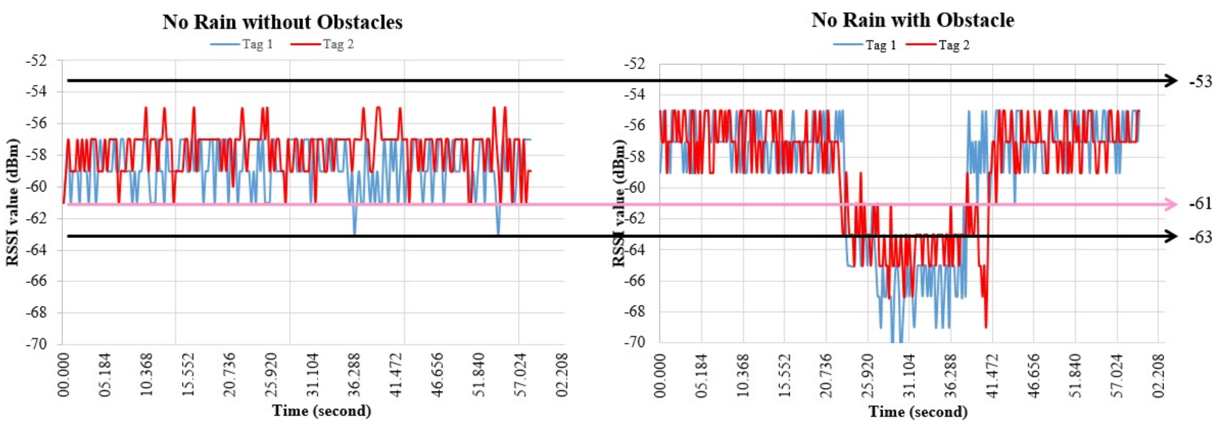


Fig. 6. The RSSI values under non-raining condition.

To tackle the problem of false detection, the same concept was also used in rainy conditions, which means the average mean of the RSSI value changes should fit within the range of more or less than 9.0% of the mean. Figure 7 shows the RSSI values collected in the on-site experiments under rainy conditions. For both Tags 1 and 2, the acceptable range of the RSSI values was between -52 to -62 dBm. Under normal situations, the acceptable range fit within the 9.0% variation, which was the same as the result under non-raining condition. Therefore, the RFFODS did not generate false detection under rainy conditions. The alarm system activated once the RSSI value collected exceeded the acceptable range.

To prove the significance of the system, T-Test and ANOVA can help to prove the significance of the RSSI value changes to facilitate the system operation. Before calculation, there were three hypotheses, which are:

$$H_0;\ U_{A1} = U_{A2} \qquad (2)$$
$$H_1;\ not\ all\ means\ are\ equal$$

$$H_0;\ U_{B1} = U_{B2} \qquad (3)$$
$$H_1;\ not\ all\ means\ are\ equal$$

$$H_0;\ interaction\ absent \qquad (4)$$
$$H_1;\ interaction\ present$$

Table 7 shows the analyzed results from Two-Way ANOVA for the comparisons between tags detection. In this case, the tag with a p-value of 0.086 is greater than the critical value of 0.005 and smaller than the critical *F*-value of 3.853. It means that H_0 cannot be rejected, which there is no significant difference between the performances of the two tags. For the *p*-values of obstacle and scenarios combination, which are smaller than 0.001, it means that H_0 can be rejected as these factors have a significant difference between groups. Therefore, it shows that the experiments were conducted in a sophisticated manner and supported the system readability and response time optimization.

After proving there is no significant difference between the tags, Two-Way ANOVA was used again to study the differences of having an obstacle and no obstacle separately for the two tags. The Two-Way ANOVA results of comparisons between presences of obstacle for Tags 1 and 2 are shown in Tables 8 and 9, respectively.. The p-values of obstacle and rain combination for each tag are smaller than 0.001, while F-values are greater than F-critical values. This means that H0 can be rejected since these factors have a significant difference between groups.

6 System Sensitivity

Based on the opinion sought from the case company, there were some commonly dropped items that were of concern, including but not limited to plastic shoes, plastic bags, plastic bottles (with liquid), plastic bins, umbrellas, and newspapers. The changes of RSSI values for each of the above item dropped onto the railway were recorded 50 times, for which an average RSSI value was calculated for every second. In this experiment, a 40-sec time duration was divided into 2 sessions, with and without a fallen ob-

TABLE 7
ANOVA table for factors significance between tags

	Sum of squares (SS)	Degress of freedom (Df)	Mean square (MS)	F value	P value	F critical
Tag	39.161	1.000	39.161	2.952	0.086	3.853
Obstacle	6275.714	3.000	2091.905	157.699	0.001	2.616
Model	223.084	3.000	74.361	5.606	0.001	2.616
Within	10506.010	792.000	13.265	-	-	-
Total	17043.969	799.000	-	-	-	-

TABLE 8
ANOVA table for factors significance between obstacle under rainy conditions (Tag 1)

	Sum of squares (SS)	Degress of freedom (Df)	Mean square (MS)	F value	P value	F critical
Tag	2986.623	1.000	2986.623	427.143	0.001	3.865
Obstacle	315.063	1.000	315.063	45.060	0.001	3.865
Model	135.722	1.000	135.722	19.411	0.001	3.865
Within	2768.870	396.000	6.992	-	-	-
Total	6218.560	399.000	-	-	-	-

TABLE 9
ANOVA table for factors significance between obstacle under rainy conditions (Tag 2)

	Sum of squares (SS)	Degress of freedom (Df)	Mean square (MS)	F value	P value	F critical
Tag	3358.203	1.000	3358.203	559.863	0.001	3.865
Obstacle	370.563	1.000	370.563	61.778	0.001	3.865
Model	172.922	1.000	172.922	28.829	0.001	3.865
Within	2375.310	396.000	5.998	-	-	-
Total	6276.998	399.000	-	-	-	-

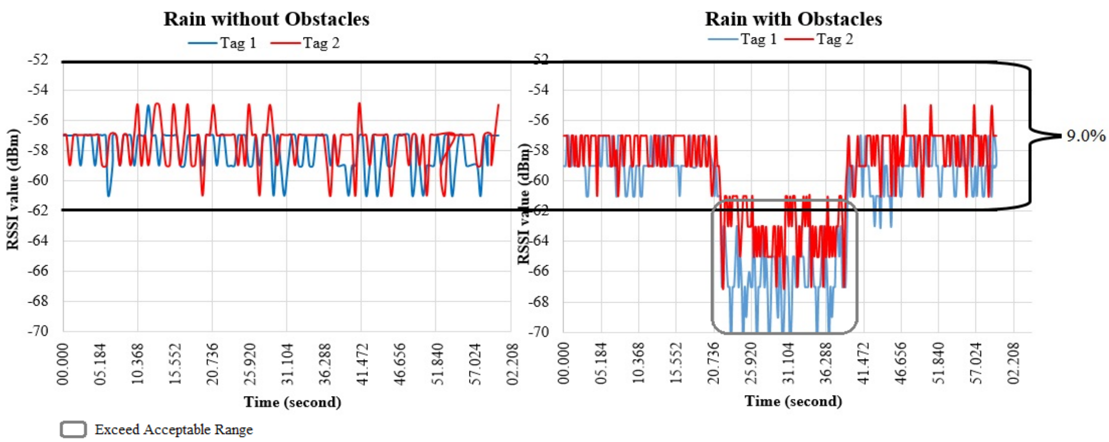


Fig. 7. The on-site RSSI values under rainy conditions.

ject. There was no fallen object involved in the first 20 seconds (i.e. 00:00 – 00:20), and then an item was dropped on the rail until the end of each experiment round (i.e. 00:21-00:40). Results of average RSSI value changes in six commonly dropped items are shown in Figs. 8 and 9.

When a large sized person (i.e. 180 cm tall) fell onto the railway, the RSSI values dropped 11%, on average, compared to that obtained in a "clear field". On the other hand, when a small person (i.e. 150 cm tall) fell, the RSSI values dropped only 7.5%, on average. Therefore, the change in RSSI values for a larger person falling onto the rail are bigger than that for a smaller person. However, in the detection checking for some common fallen objects, it was found that the RSSI values were quite steady (e.g. plastic shoes and newspapers) but had an increasing number of missed signals during the period in which the object was falling (e.g. umbrella and plastic bag). Typically, the larger the mass or size of items, like plastic bottles (with liquid) and plastic bins, the weaker the RSSI values measured. It could be concluded that the proposed system is valid for sensing different sized people, but the algorithm needs refining for determining the continuously missing signals for objects.

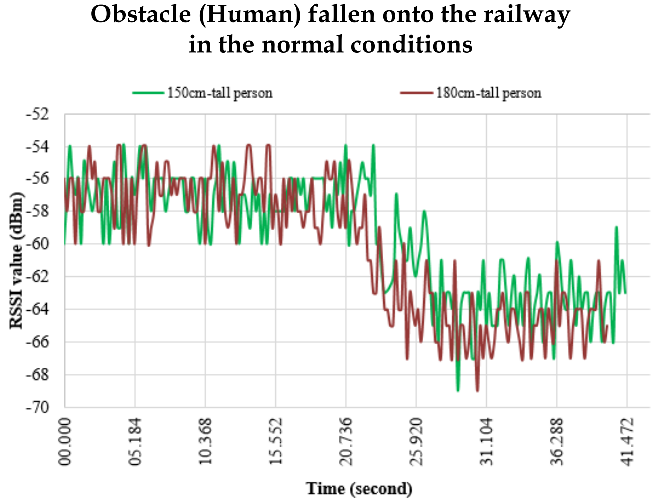


Fig. 8. Value changes in average of the RSSI value when detecting objects (human) by using the set B.

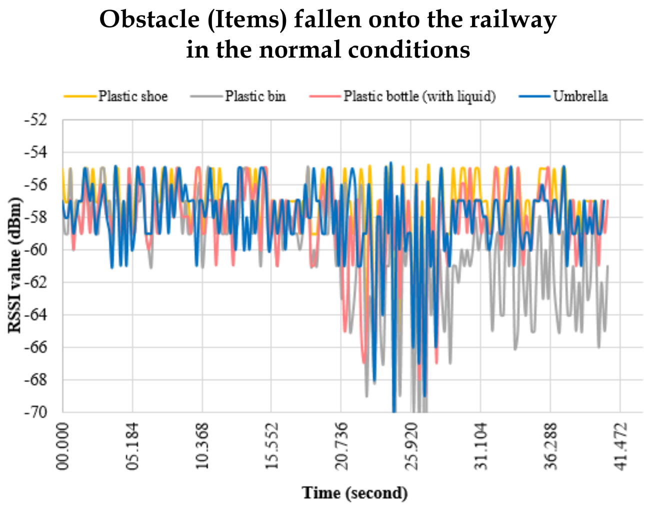


Fig. 9. Value changes in average of the RSSI value when detecting objects (item) by using the set B.

7 Conclusion

It can be concluded that the RSSI values with significant differences could facilitate the proposed RFFODS operation in fallen object detection. To compare with the current LRV detection system, RFFODS uses a single detection source via RFID devices. If the RSSI value exceeds the acceptable range, it will send a message to alarm system automatically to alert the responsible parties. Passengers and station staff will not be the main sources of detection. This system ensures fast response time by automation, eliminates duplicated process with an immediate alert to the responsible parties, and, hence, the detection procedure is greatly simplified.

To sum up, this research project focused on developing an FODS for railway operation and provided a comprehensive study and results analysis through off-site and on-site experiments. Reviewing the current Light Rail detection operation and process, other than automation, response time, and accuracy were the vital elements for implementation. Study of the proposed RFFODS was proven to be successful after being examined in the NDL Corp. By reviewing the existing train operation system, the importance of automation was revealed. The proposed RFFODS was designed for more efficient and accurate performance with lower manpower involved. Statistical methods were used for proving the feasibility and evaluating the performance under different critical scenarios (i.e. raining and obstacle presence).

An effective FODS is proposed and is feasible for immediately dealing with fall accidents. It is suggested that further work should focus on developing the functionality of the system provided, such as obstacle identification and location. Also, further experimental testing can be conducted by considering more variables, including extreme temperatures in the environment and conditions, enhanced design setting (i.e. multiple antenna or antenna arrays, platform-based system rather than on-board system), and more testing obstacles falling onto the track (i.e. several sizes of obstacles, humans, and dummies). Last, but not least, the enhanced system needs robustness testing and dynamic antenna adjustment with heuristic optimization procedures [40], such as particle swarm optimization algorithms [41, 42].

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