Development of Indoor Automatic Parking System Model with Real-time Database

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ABSTRACT

With the increasing number of vehicles nowadays, the problem of parking spaces has been on the rise, especially in major cities. When searching for an empty parking space, it is usually time consuming for a vehicle's user as he or she has no prior knowledge on the actual location of the empty parking space. With the development of the web-based remote monitoring system to monitor the empty parking spaces, their location and vehicles information, the problem of parking spaces can be effectively resolved. This paper presents a research work to develop an Automatic Parking System (APS) model based on sensors technology to provide useful information to the user, specifically in identifying and determining the appropriate vehicle parking space. The parking space information can be monitored in detail to include the locations of available empty parking space at specific time period, vehicle as well as its owner's information. Four design concepts were shortlisted based on a morphological analysis. The selected design Concept 3 is able to exhibit a three-degree of freedom (3-DOF) movements using a conveyor as well as a rack and pinion drive system. Radio frequency identification (RFID) sensors were used to detect the objects in the APS while Arduino microcontroller was chosen and implemented as the brain of the monitoring system. The internet of things (IoT) was embedded together with the system to enable the physical object (vehicle) to be connected to the virtual world (internet). The web-based remote monitoring system prototype was developed and built to verify the integrity of the system and show the functionality of remote based APS. Through this design of the APS, useful information such as the available parking spaces, vehicle's details and parking duration can be determined and stored in a database.

Keywords: *Smart city, radio frequency identification, internet of things, parking database*

1.0 INTRODUCTION

The existing design of most conventional parking system is typically too big, uses significant amount of space and the fact that most of the building floor areas are being utilized for driving lanes. To solve this problem, the conventional parking concept needs to be replaced by an automatic parking system (APS) to efficiently utilize the space usage and reduce the time taken to find an empty parking space [1]. The APS often utilizes a computer-controlled system of pallets, conveyors, shuttles carriers and lift in transporting cars from the arrival level to a parking space location and vice versa without human assistance [2-3].

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APS can save up 40% more space compare to conventional garage to fit same number of cars. This is because there is no ramp, few stairs, no patron elevators, and thinner slabs in APS design. Ramps are needed for conventional parking to connect from lower ground to upper ground and space for slotting a car to a specific or selected parking space [4]. Another advantage of APS is the vehicle security in which cars are stored inside the designed building after the driver has left the car to be lifted into a parking space which is done automatically without the assistance by a human operator. APS is ideal for office buildings, residential buildings, airports and hotels because people with their cars often flocked to these places, which generally implies that more parking spaces are required [5].

2.0 HISTORY OF PARKING SYSTEM DESIGN

The world first automatic parking system (APS) based on an auto-mechanical parking device was developed by Max Miller in New York, 1925 [1]. The purpose of APS is simply to lift a car using hydraulic but it was never used until 1941. In 1941, when the city of New York is crowded with cars, Light first attempted to create a vertical car park that stacked three cars on each side on top of each other for a total of 6 slots [1]. After a year, the automated garage was invented by Austin and the system is called *Roto Parks*, *Pigeon Holes* and *Bowser*. After several years of design and development, a number of changes were made to improve the automated car park. In 1964, Eric Jaulmes invented the APS that is somewhat similar to the one that is currently seen. His system used a valet to drive a car to the elevator which will then take the car to a parking spot and later park the car in the empty space. Upon returning mode, the valet will stop to another spot for the car to be returned if requested.

There are two main components in designing the APS, namely the mechanical and electrical components. A number of approaches based on different designs and other related components has been developed. A prototype of the APS developed by Vishnoi *et al.* has two main distinct structures which are the parking rack and robotic arm [3]. The robotic arm has a 3-DOF configuration which enables it to move in three different directions, i.e., x, y and z-axes. A ball screw mechanism was used for all the three robot movements and three respective stepper motors were employed as the main actuators to move the arm. The system used programming logic controller (PLC) as the main controller for controlling robotic arm when the signal from sensor was received. The sensors used in his prototype were the infra-red (IR) sensor and RFID sensor. Three pairs of the IR sensors were attached to each axis of the robotic arm, respectively to get the feedback information about the movements [6-8].

RFID device contains a wireless microchip that is used to mark and identify an object for automatic identification. RFID systems consist of a reading device which is known as reader and its tag. The reader is used to store the read data on the tag that has a unique data such as the car flat number. There are three types of tags, which are the passive semi-passive and active tags. The passive and semi-passive tags can operate without using to a power source. The tags are triggered by an electromagnetic wave that is transmitted from the reader. The passive tag is cheap compared to the active counterpart because it can only store a small amount of data and has a lower operating range. Meanwhile, an active tag uses a battery as the power source to operate it. Active tag has a higher operating range and can transmit according to its own wave. Examples of the RFID application can be seen in modern passport, device to track cattles and others [9].

RFID reader and tags need to be of same frequency to communicate with each other. There are three types of frequency range of the RFID reader, namely the low frequency (LF), high frequency (HF) and ultra high frequency (UHF). The LF RFID will have a high wavelength to enable it for high penetration power application. The LF RFID is able to penetrate metal but it has a low operating range and has a slower signal reading. Its reader level is 125 kHz and the operating range is up to 10 cm. For HF, it has a low penetration power for metal but it has a higher operating range compared to LF. HF RFID frequency is typically at 13.56 MHz [10-11].

3.0 DESIGN OF PROTOTYPE

3.1 Function Decomposition

The operation of the APS prototype is divided into five separate functions and attributes related to sensors arrangement, entrance mechanism, movement mechanism, lifting mechanism and lastly, slotting the vehicle into parking space.

3.2 Morphological Analysis

Morphological analysis is a tool to generate a new concept as it allows us to find possible solutions to complex problems by listing the functions of the product that will be developed and think about the variations of solution. The solution is listed in the form of a table as shown in Table 1. The attributes of the product are sensor arrangement, entrance mechanism, movement mechanism, lifting mechanism and the slotting mechanism. Up to four options or solutions were listed for each function. The selected design *Concept 3* for the APS was drawn based on the morphological analysis of the combination table as shown in Figure 1.

Table 1: Concept combination based on the morphological analysis

Function	Option 1	Option 2	Option 3	Option 4
RFID Layout	Above Parking	On then Roof	Below the car	On the Side
Entrance	Automatic Door	Automatic Gate		
Horizontal Movement	Gear and Belt	Conveyor	Screw Drive	Trolley
Lifting	Scissor Lift	Pulley System	Scew Drive	Rack& Pinion Lift
Slotting the car	Rack & Pinion	Conveyor	Trolley	

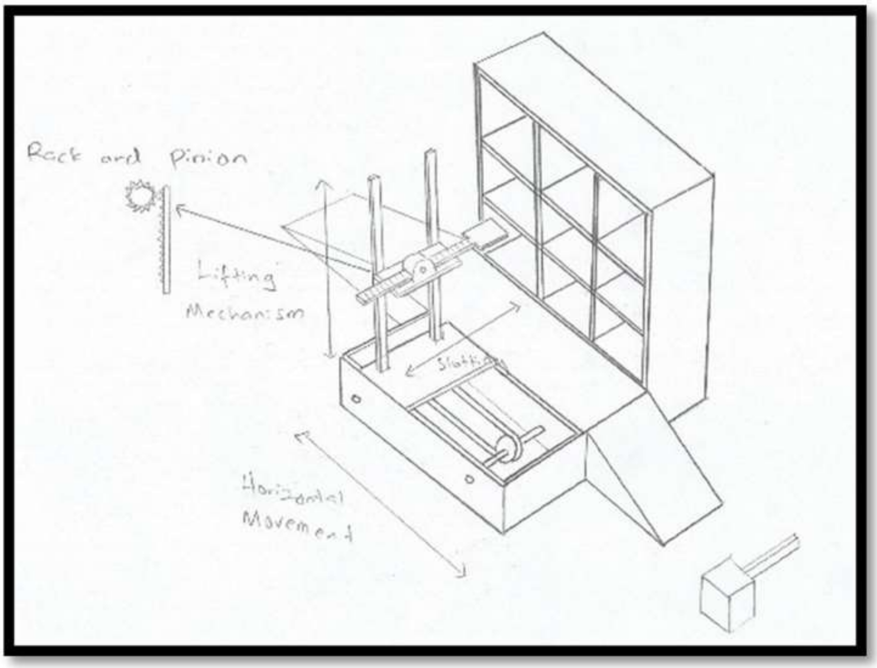

Figure 1: Design *Concept 3*

3.3 Concept Evaluation

In concept evaluation, the criteria were discussed to decide how the scoring of the concept was done. The marks given were based on the importance of the criteria. The higher the mark, the more important is the criterion. After that, the total marks for each design concept were calculated, the design concept with the highest marks will be selected, though it is still subjected to further improvements. Table 2 shows the scoring method or selection of the design concept. Based on the concept scoring table, design *Concept 3* obtained the highest scoring with 3.98 points. This is followed by *Concepts 1* and *4* with 3.28 and 2.90 points, respectively. The lowest score is for *Concept 4* which produces 2.70 points with respect to the datum design as reference. *Concept 3* was chosen for further development into the final design. However, *Concept 3* is far from being a true final design.

Table 2: Evaluation (scoring)

No.	Selection Criteria	Weightage	Datum	Design Concept			
				1	**2**	**3**	**4**
		Performance (0.50)					
1.	Stability	0.20	3	3	3	3	4
2.	Machine simplicity	0.15	3	3	2	4	2
3.	Time taken	0.15	3	4	4	5	5
		Fabrication (0.40)					
1.	Material availability	0.05	3	4	2	4	5
2.	Fabrication time	0.10	3	4	2	5	1
3.	Material cost	0.10	3	2	4	5	2
4.	Ease of fabrication	0.15	3	4	2	4	2
		Aesthetic (0.10)					
1.	Design appearance	0.03	3	3	2	3	2
2.	Size	0.07	3	2	3	2	2
	Total mark	1.00	3.00	3.28	2.70	3.98	

3.4 Concept Development

The initial concept design has been drafted using *SolidWorks*. At this stage, the material, dimension, output requirements and feature has not been fully considered yet. The design will be further improved after some modifications and further engineering analysis. This research aims to develop an APS that is able to perform the three-DOF movements with reference to the *x*, *y*, and *z*-axes. The prototype must be able to lift a toy car sized model with a dimension of about 50 mm x 30 mm x 10 mm, having a maximum weight of 0.1 kg and it can store up to nine cars. The RFID reader used in this prototype is *Mifare RFID Module RC522*. It is a HF RFID reader operating at 13.56 MHz and the range of signal is 3.4 mm. Based on this information, the size of the parking rack was determined as shown in Figure 2. The material used to build the parking rack is a plywood with a thickness of 5 mm.

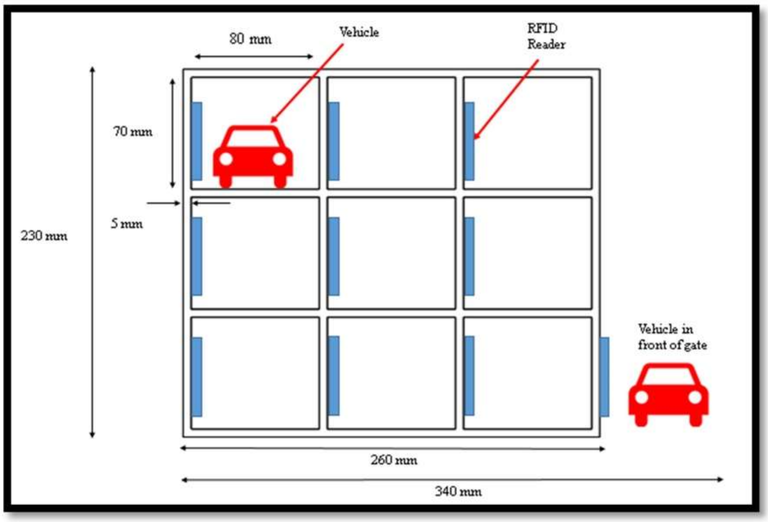

Figure 2: Dimensions of parking rack

3.5 Final Model Design

Figure 3 shows the final design of the proposed APS model. It consists of two main parts, which are the parking rack and robotic arm. The robotic arm consists of three mechanisms which are related to the lifting mechanism, slotting mechanism and a conveyor that enable the robotic arm to move in three-DOF which are the *x*, *y*, and *z*-axes movements.

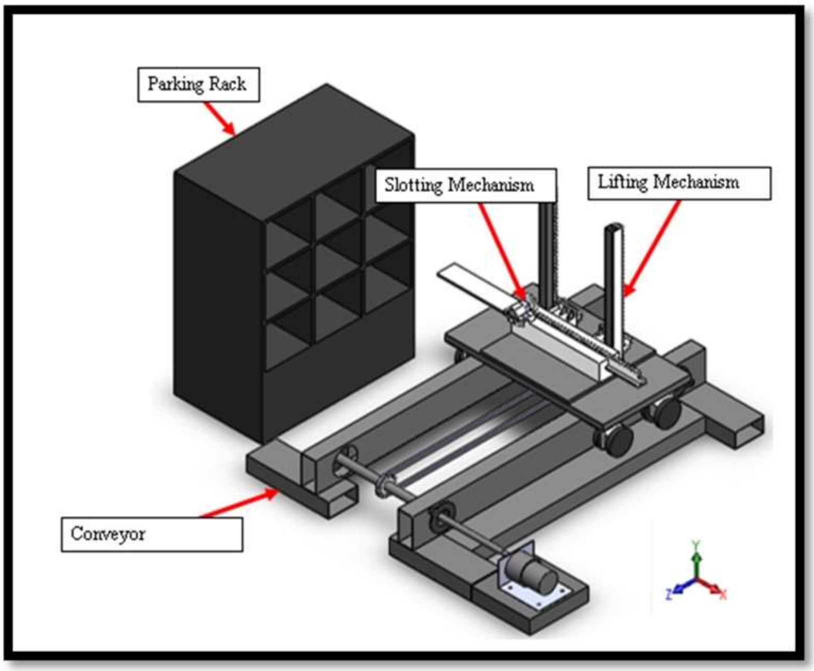

Figure 3: Final design

4.0 RESULTS AND DISCUSSION

4.1 Engineering Analysis

This section discusses about a series of engineering analysis done on the final design of APS mechanism after some modifications. The purpose of this engineering analysis is to determine the factor of safety (FOS) of the mechanism to be fabricated to achieve the mechanism objectives. By using *SolidWorks*, the maximum stress and displacement of the slotting mechanism body were calculated and the FOS determined. For the shaft, the shear stress and bending moment were also obtained analytically to determine the FOS.

4.2 Stress Analysis

Stress analysis was conducted to determine the critical points and a segment in rack and pinion holder for slotting a toy car into parking slot. The FOS of the critical points were also computed to determine the structure can withstand the applied force. If the FOS is less than 1, the design is deemed failed to withstand the applied force and redesign of the component is needed to change the material with higher yield strength.

The chosen material for the slotting mechanism is a thermoplastic which is *Acrylonitrile butadiene styrene* (ABS); it has light weight and high toughness properties. Based on the design specifications, the total weight of the toy car with the mechanism is about 1 kg and hence the material needs to be light and strong enough to lift the load. Thus, ABS is considered the most suitable material for the slotting mechanism. Based on Figure 4, the maximum *Von Mises* stress was found to be about 0.51 MPa underneath the platform and the mechanism has a FOS of 86.27.

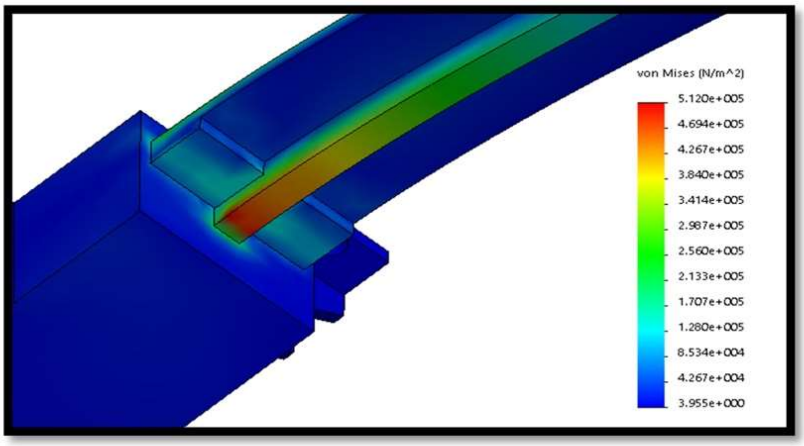

Figure 4: FEA *Von Mises* stress gradient isometric view (minimum length)

4.3 Shaft Analysis

The bending moment diagram was drawn to determine the critical stress acting on the shaft. Based on Figure 5, the most critical location is at point B with a bending moment of 0.204 Nm. The yield strength of the mild steel is 370 MPa, the diameter of shaft is 0.012 m and the torque of shaft is 0.2548 Nm. Based on this information, the maximum stresses can be obtained.

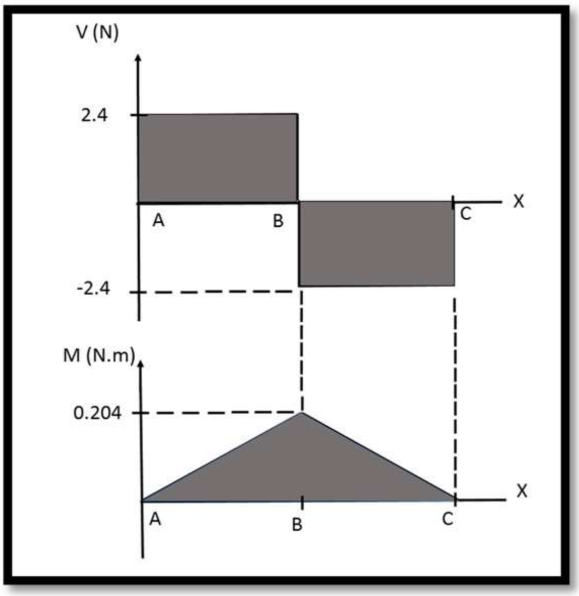

Figure 5: Bending moment diagram

4.3 Sensor Placement Accuracy

To measure the proposed APS performance, the time taken for one complete cycle for the RFID sensor to detect the parked car was recorded as shown in Table 3. It is also shown in Figure 6, the relationship between the time taken and number of RFID sensors is directly proportional.

However, from the above graph, the time taken for one complete cycle which is 2.5 s is regarded a bit too long. If the available parking spaces are 30, therefore the average time is about 1 min. This means that after the reader detects the first tag, it will take 1 min to read another tag which is a little bit slow. Besides that, the detection range analysis was also conducted to compare the two types of the RFID tags.

Table 3: RFID sensor accuracy

Number of RFID sensor	Time taken for one complete cycle (s)			
	1	2	3	Average
1	2.5	2.7	2.6	2.6
2	5.2	5.0	5.1	5.2
3	7.5	7.7	7.5	7.6
4	10.6	10.4	10.7	10.6
5	12.7	12.5	12.6	12.6
6	15.1	15.0	15.1	15.1
7	17.7	17.6	17.6	17.6
8	20.9	20.3	20.2	20.5
9	22.7	22.5	22.5	22.6

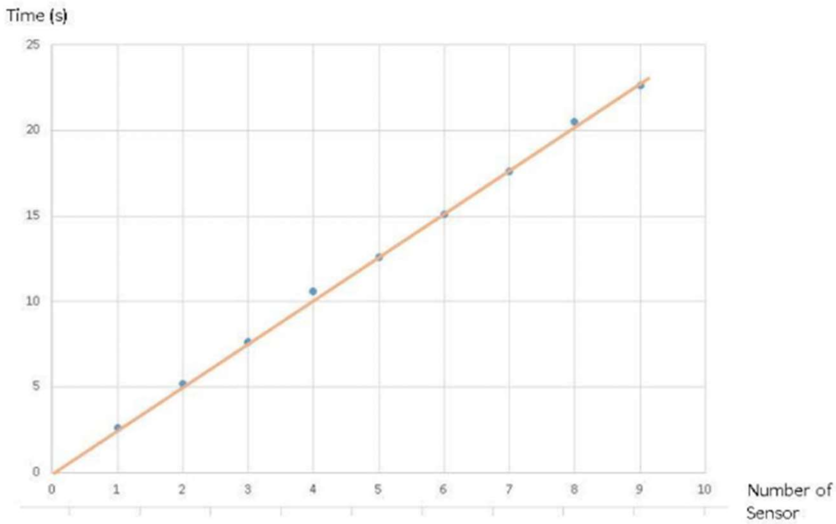

Figure 6: The relationship between time taken and the number of sensors used

From the results shown in Table 4, the RFID tag card type has a bigger range compared to the keychain type of tag. This is due to the size of the card which is rectangular in shape. Next, the position or placement of the tag at the parking space may affect the detection process of the approached car as illustrated in Figure 7.

Table 4. Detection range analysis

RFID tag type	Detection range (mm)			
	1	2	3	Average
MiFare Classic 4k Card	3.5	3.3	3.4	3.4
MiFare 4k Keychain	2.0	2.1	2.0	2.0

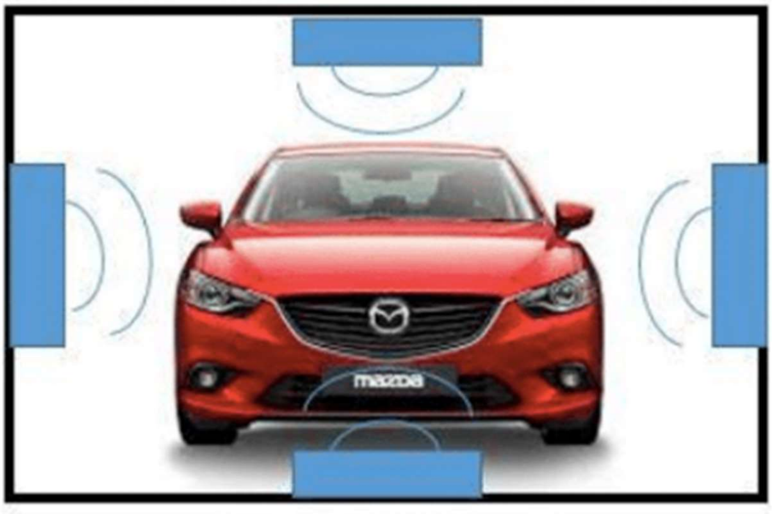

Figure 7: The possible positions of the RFID placements

To determine the best position of the RFID tags, three position have been evaluated as shown if Table 5. It can be seen that the success rate of the RFID detection depends on the position or placement of the sensor. The right and left positions success rate is 100% while top position success rate is 37%. This is due to the fact that the parking space is too small compared to the size of the RFID reader. This situation might cause the car to hit the sensor and thus cause the RFID connection to transfer the data to the host computer. Figure 8 shows the information at the user interface for the parking space.

Table 5: Tags position analysis

RFID reader position	Success rate of the RFID reader and tag detection		
	Total trial	Total RFID tag read	Percentage of RFID read success
Top	100	37	37%
Right	100	100	100%
Left	100	100	100%

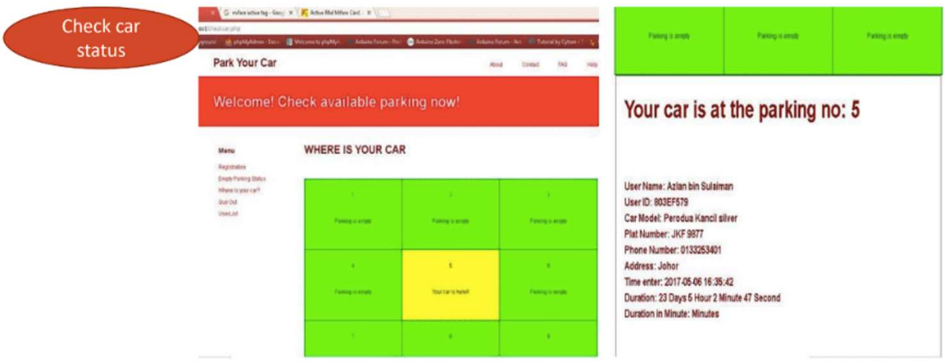

Figure 8: Information from the database at the user interface

5.0 CONCLUSION

A small prototype model of the APS has been designed and developed to demonstrate the usage of RFID sensors for vehicle tracking. The *Von Mises* stresses of the mechanism were analyzed at the slotting body. The mechanism was proven to be able to withstand a load of 0.1 kg with a factor of safety (FOS) of 18.8 at maximum length and 86.27 at minimum length. The FOS of the shaft is calculated using distortion energy theory. Based on the result, the most critical point was found to be at point B (based on the bending moment diagram of Figure 5) but not critical enough for the failure to occur. The accuracy of the RFID sensors has also been analyzed. The factors that are deemed to affect the detection of car at the parking space are the type of the RFID tag used, number of the RFID sensors placed at each parking lot and positioning of the RFID sensors at each parking lot. The orientation of the RFID tag also improves the detection rate in which the detection width is about 8 mm and a height of 6 mm from the antenna. Therefore, the RFID tag must be placed in parallel to the RFID reader.

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