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RFID Enabled Automatic Parking System

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ABSTRACT

Lack of parking space has become major contributing factor to traffic congestion which may affect the environmental condition due to incalculable amounts of wasted fuel and carbon emission. Congestion and parking are interrelated as looking for parking space may create additional delay and impair local circulation. The proposed automatic parking system which embedded with radio frequency identification (RFID) and internet of things (IoTs) module will introduce a monitoring platform for the parking space. This intelligent parking system makes it possible for the drivers to obtain information beforehand through their mobile hand phone application or any display available. This paper describes the mechanical design of automatic indoor parking space with the advancement of sensor networks application known as RFID. The design criterias were studied to develop a parking prototype which dealing with number of degree of freedom as well as movement mechanism. The result presented at the end of this paper was evaluated from the engineering analysis using the developed parking prototype to meet system performance as well as design safety factor.

1. Introduction

The existing design such as conventional parking concept is relatively big and used a lot of space and most of the space of the building is used for driving lane. To solve the problem, the conventional parking concept needs to be replaced by automatic parking system to utilize the usage of space and reduce the time taken to find empty parking. The automatic parking system (APS) are utilizing computer controlled system of pallets, conveyors, shuttles carriers and lift in transporting cars from the arrival level to a parking space and vice versa without human assistance.

APS can save up 40% more space compare to conventional garage to fit same number of car. This is because there is no ramp, few stair, 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 car to a specific or selected parking space

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Another advantage of APS are vehicle security, cars are stored inside designed building after driver left the car to be lifted into parking space which is done automatically without assistance by human. Automatic parking is ideal for office building, residential building, airport and hotel because this place that have many visitor which mean more parking spaces are required.

2. Design Mechanism and Components

The world first automatic parking system is developed by Max Miller in New York, 1925. The purpose is simply to lift a car using hydraulic system but it was never used until 1941. In 1941, when the cities of New York is crowded with cars, Light was the first attempt to create a vertical park that stack three cars on each side on top of each other for total of 6 slots After one year, automated garage are invented by Austin and the system are called Roto parks, Pigeon Holes and Bowser [1].

After several years, design and development are changes to improve the automated car park. In year 1994, Eric Jaulmes invented automated parking system that is similar to current technology. His system used valet to drive a car to elevator and the elevator will take the car to parking spot, the valet then will park the car in the empty space. When return down, valet will stop to another spot to the car to be returned if requested [2].

2.1 Mechanical Component

There are two main components in designing the automatic parking system which includes mechanical component and the other one is electrical component. Different design has different components and approach. A prototype of automatic car parking developed by Kshitiz Vishnoi had two main structures which are parking rack and robotic arm. Besides, the robotic arm has three degree of freedoms which is able to move in three different directions that X, Y and Z-axis. Ball screw mechanism is used for all the three movements of robotic arm and three stepper motors are employed to move the arm. The system used programmable logic controller (PLC) as main controller for controlling robotic arm when the signal from sensor is receive. The sensor used in his prototype is IR sensor an RFID sensor. Three pair of IR sensors are attach to either end of each axis of robotic arm movement respectively to get feedback of the movement [3].

2.2 Electrical Component

Radio Frequency Identification (RFID) device are wireless microchip that used to mark object for automated identification. RFID systems consist of reading device which is known as reader and tags. The reader is used to store read data on the tags and tags usually store a unique data such as car flat number. There are three types of tags which are passive tags, semi-passive tags and active tags. Passive tags and semi-passive tags can operate without using its own power. The tags triggered by electromagnetic wave transmitted from the reader. The passive tag is cheaper than active tag because it can only store small amount of data and have lower operating range. Meanwhile, active tags used battery as power source to operate their own. Active tags have higher operating range due to tags can transmit their own wave. Example of RFID applications can be seen in passport, tracking cattle and others [4-12].

RFID reader and tags need to be same frequency to communicate each other. There are three type of frequency range of RFID reader which are Low frequency (LF), High Frequency (HF), and Ultra High Frequency (UHF). Low frequency (LF) RFID will have high wavelength. This will enable the LF RFID to have high penetration power. LF RFID are able to penetrate metal but it have low operating range and have slower signal reading. LF RFID reader level is 125 KHz and the operating range up to 10 cm. For high frequency (HF), it has low penetration power to penetrate metal but it has higher operating range compare to lower frequency. HF RFID use 13.56 MHz [13].

3. Prototype Design Concept

3.1 Function Decomposition

The operation of prototype is divided into five separate functions and attributes which are sensor arrangement, entrance, moving, lifting as well as car slotting mechanism.

3.2 Morphological Analysis

Morphological analysis is a tool for generating new concept, it allows us to find possible solutions to complex problems by listing the function of the product that will be develop and think about the variation of solution. The solutions are listed in form of table as shown in figure 1. The attributes of the product are sensor arrangement, entrance mechanism, movement mechanism, lifting mechanism and lastly is slotting mechanism. Up to four options or solutions are listed for each function. The third design concept for the prototype is drawn based on the concept combination table as shown in the following figure 2.

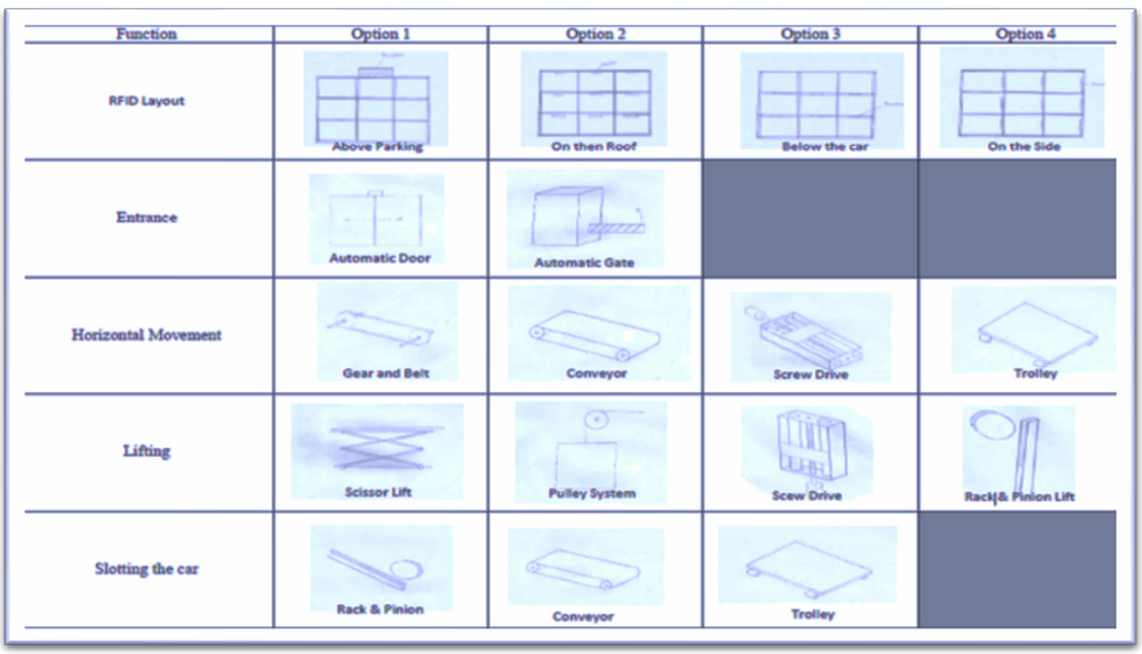

Fig. 1. Functional decomposition in design concept

3.3 Concept Evaluation

In this concept evaluation, the design criteria is determined in order to decide how the marking of the concept to be done. The marks given are based on the importance of the criteria. The higher the marks, the more important the criteria it is. After that, the total mark for each design concept are calculated, the design concept with highest marks will be selected and will be further improve. Table 1 illustrates the scoring method for selection of design concept. The design concept which has highest total mark is selected and further improved. Based on the concept scoring table, conceptual design number 3 obtained the highest scoring with 3.98 points followed by conceptual design number 1 and 4 with 3.28 and 2.90 points respectively. Lowest score is conceptual design number 4 with 2.70 points with respect to datum design. Therefore, conceptual design number 3 is chosen for further development into the final design.

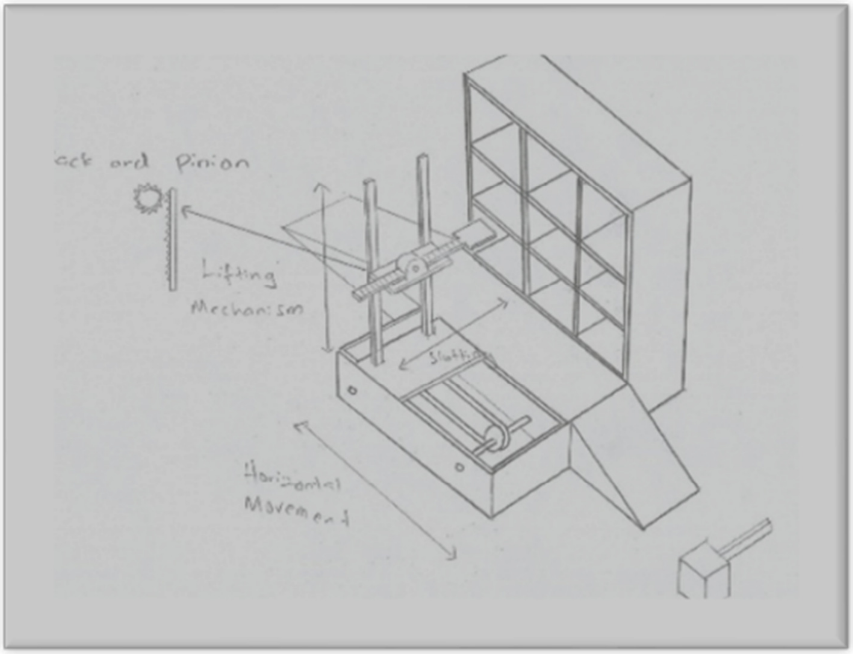

Fig. 2. Selected prototype design mechanism

Table 1
Evaluation of prototype design scoring

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**	**2.90**

3.4 Concept Development

Initial prototype conceptual design has been draft using SolidWorks®. At this stage, the material, dimension, output requirements and feature has not been considered yet. The design will be further improved after modification and engineering analysis. This research aims to develop an automatic parking system that is able to do three degree of freedom movement which are x, y, and z-axis movement. The prototype must be able to lifting a toy car size with dimension of 50mm x 30mm x 10mm with maximum weight of 0.1 kg and can store up to nine cars. RFID reader used in this prototype is Mifare RFID Module RC522. It is a high frequency type of RFID reader which is 13.56 MHz and the range of signal is 3.4 mm [14-15]. Based on this information, the size of the parking rack is determined as shown in the following figure 3. The material to build the parking rack is plywood with 5mm thickness.

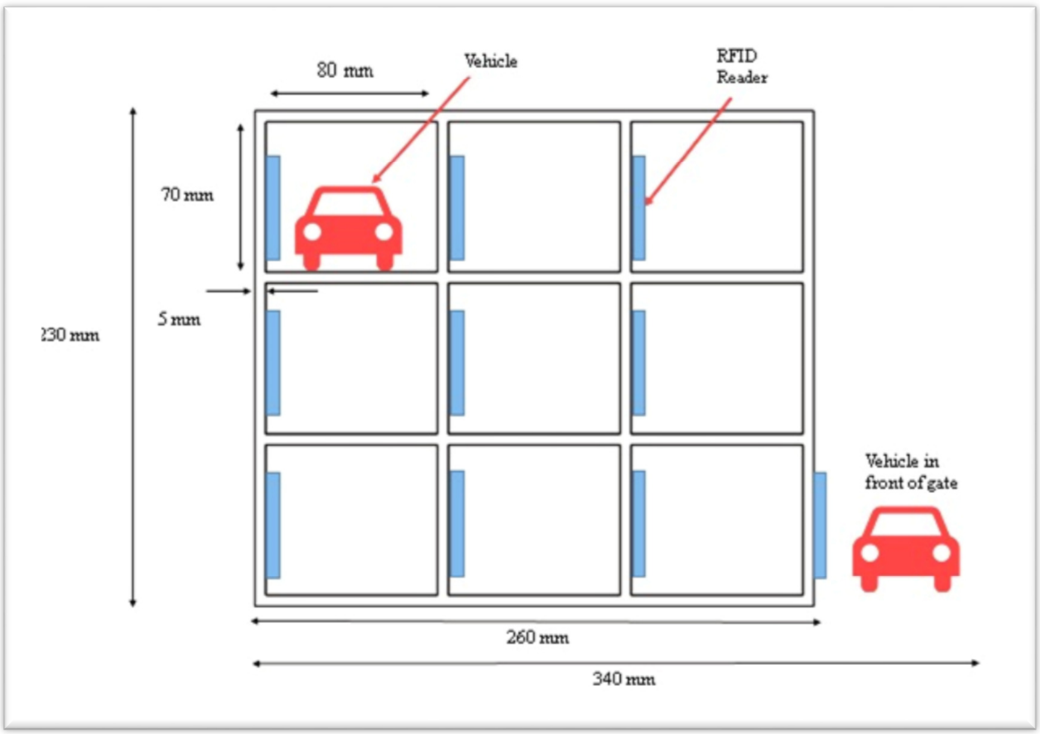

Fig. 3. 2D CAD drawing of parking prototype

3.5 Final Model Design

Figure 4 shows the final design of automatic parking system. It consists of two main parts which are parking rack and robotic arm. The robotic arm has three mechanisms which are lifting mechanism, slotting mechanism and conveyor that enable itself to move in three degree of freedom which is *x*, *y*, and *z*-axis movement.

4. Results and Discussion
4.1 Engineering Analysis

This section discusses about a series of engineering analysis done on the final design of automatic parking system mechanism after the modification. The purpose of this engineering analysis is to determine factor of safety (FOS) of the mechanism to be fabricated to achieve its objectives. By using SolidWorks®, the maximum stress and displacement of the slotting mechanism body are calculated and FOS is determined. For the shaft, the shear stress and bending moment are calculated analytically to determine its factor of safety.

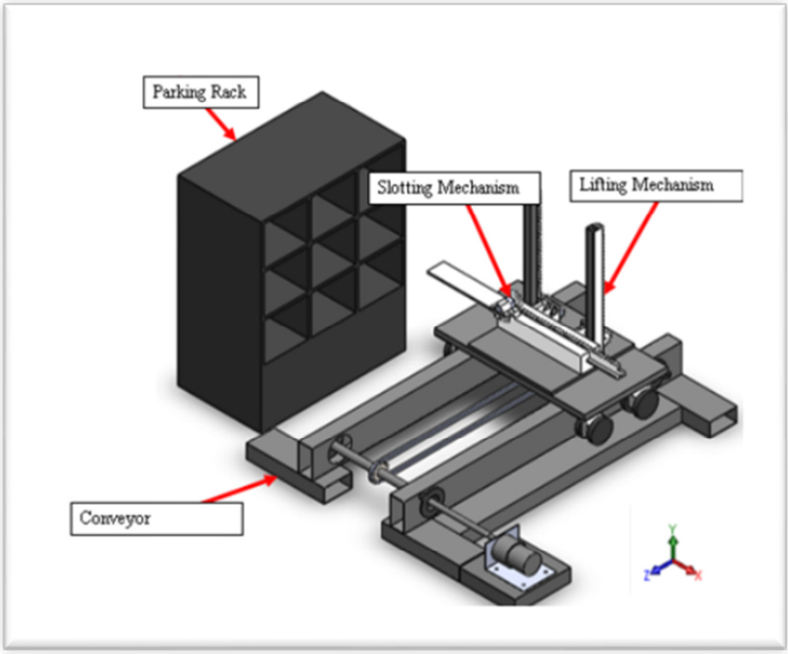

Fig. 4. 3D CAD drawing of parking prototype

4.2 Stress Analysis

Stress analysis is conducted to determine the critical points and a segment in rack and pinion holder for slotting a toy car into the parking slot. The safety of factor of critical points is also calculated to determine either the structure can withstand the force applied to or not. If the safety factor is less than 1, the design fails to withstand the force applied and it need to be either redesigned the component or change the material with higher yield strength.

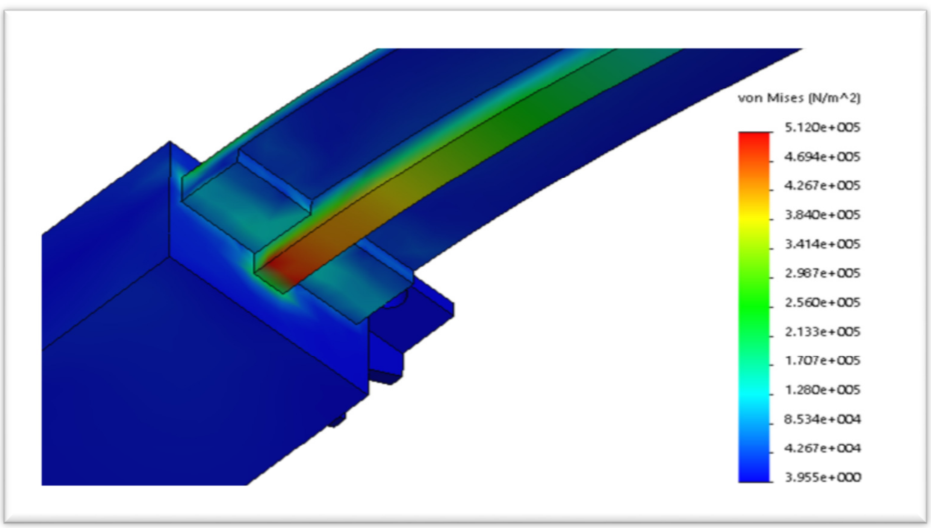

Fig. 5. Von Mises stress gradient isometric view (minimum length)

The chosen material for slotting mechanism is thermoplastic known as Acrylonitrile butadiene styrene (ABS) due to its characteristic of light weight and high toughness. Based on design specification, the total weight of toy car with the mechanism is roughly 1 kg, so the material needed to be light and strong enough to lift a load. Thus, ABS is the most suitable material for the slotting mechanism. Based on figure 5, the maximum Von Mises stress is about 0.51 MPa at the bottom platform and it has a safety factor of 86.27.

4.3 Shaft Analysis

Bending Moment Diagram is drawn to determine critical stress acting on shaft. As shown in figure 6, the most critical bending is at point B with the result of 0.204 N. The yield Strength, S_y of Mild Steel is 370 MPa and the diameter of shaft is 0.012 m respectively. The torque of shaft is 0.2548 N.m.

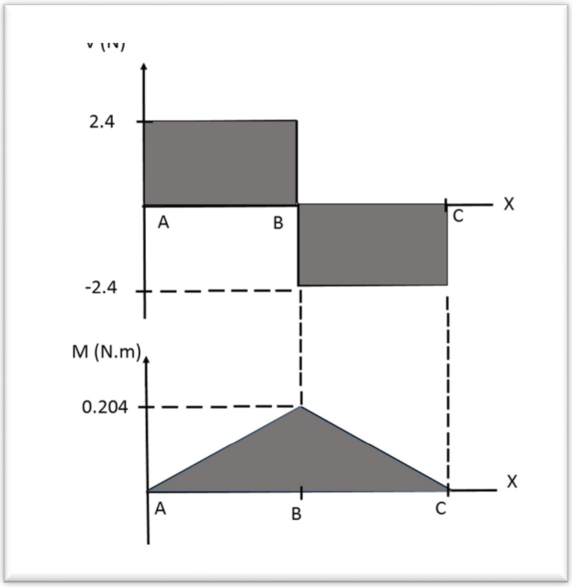

Fig. 6. Bending moment diagram

Bending Stress,

$$\sigma_b = \frac{32M_B}{\pi d^3} = 1.2 \text{ Mpa} \quad (1)$$

Shear Torsional Forces,

$$\tau = \frac{16T_B}{\pi d^3} = 0.75 \text{ Mpa} \quad (2)$$

Distortion Energy Theory,

$$\sigma' = \sqrt{{\sigma_b}^2 + 3\tau^2} = 1.42 \text{ Mpa} \quad (3)$$

Based on equation 1 to 3, S_y is higher than σ'. Thus, the failure on shaft will not occur.

5. Conclusion

This paper presents the mechanical design of a small prototype for automated parking system that was developed to demonstrate the usage of RFID sensor and incorporated IoT module for vehicle tracking as well as monitoring. The Von Mises stresses of the mechanism were analysed at the slotting body. The mechanism of the prototype is proven to be able to withstand a load of 0.1 kg with safety factor 18.8 at maximum length and 86.27 at minimum length respectively. The safety factor of the shaft is calculated using distortion energy theory. Based on the result, the most critical point is at point B but it was not critical enough for failure to occur. For automatic parking system, not only the sensor integration is important in order to provide useful information to the drivers, but its design components such as conceptual mechanical design and the placement of sensors or RFID tags and reader may affect the overall system performance.

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