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Design, Simulation, and Implementation of an Automated Lead Screw Based Multilevel Car Parking System

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Abstract

Nowadays space has become a very big problem in big towns and cities. In the era of miniaturization, it's become a very crucial necessity to avoid the wastage of space in big companies, markets, apartments, etc. Here we proposed a solution named automated lead screw based multilevel parking to solve this problem. This motorized car parking system can minimize the area for parking cars. We designed and simulated on the concept of lead screw lifting method and both sides cell after cell parking which is modernized, more efficient and even a space-saving one. This paper gives the information to develop a reduced working model of a car parking system for parking 16 cars within a parking area of 0.542 m². This also aims to develop an automated parking system prototype which will be efficient with minimum cost for densely populated cities in Bangladesh.

Keywords: Automation, Simulation, Stepper, Parking, Lead Screw.

1. Introduction

Traffic jam is a common phenomenon in our country especially in big cities like Dhaka, Chittagong, and another divisional town area. In various densely populated cities in Bangladesh, one of the most challenging and difficult issues is the management of traffic problem. As the population is increasing, the number of vehicles on the roads is also increasing leading to an insufficient area to park these vehicles. Since there is no planned parking facility in these Cities, vehicle operators stopping their vehicles at any place whenever they need. Recently at Chittagong New Market, Govt. made a semi-automated multilevel car parking system. Inspiring this parking system we aimed to design and implement a fully automated multilevel parking system.

2. Literature Review

The first multi-level parking system was build in 1918 for the Hotel La Salle at 215 West Washington Street in the West Loop area of Downtown, Chicago, Illinois. It was designed by Holabird and Roche. The Hotel La Salle was destroyed in 1976, but the parking structure remained because it had been designated as preliminary landmark status and the structure was several blocks away from the hotel.

Various types of parking systems are available now all over the world. While doing a survey we have found that this automatic car parking system has been proposed by various researchers using different techniques. The author in **[1]** developed microcontroller-based four levels Automatic Car Parking System. The wooden structure has been used for the demonstration of this prototype. Here the elevator is a conveyor rope system which pulls up the slot and actuates by a DC motor bottom of the prototype. In **[2]** Automated parking slot detection and parking system have been introduced which has two gates named Entry and exit. This system not only detects the empty slot but also can control the counter system required for parking management.

In **[3]** Microcontroller 89s52 based eight-cell car parking system has been expanded. Infra-red sensors which are placed on each of the floors, to sense the cars and detect which slot is empty. Further instructions come from the input and the DC motor runs as a parking lift model. The author in **[4]** worked with one-sided lead screw based lifting system including eight cells. This system has three different DC motor to control the X, Y and Z-axis movement.
Rotatory parking system has been developed in **[5]** based on circulating chain and sprocket. The entire parking cells rotates with the vehicles and the customer picks the empty one. Another parking system prototype in **[6]** RFID based platform rotatory parking system. This project is designed for automatically parking a car into the desired parking spot in a multi-floor parking lot. Lots are designed surrounding the central circular basement. There is also an RFID module that will provide security as users who have authority can swap the RFID cards and get entry otherwise not.

From the review of a study by P. Bhauguna (2009) **[7],** Automatic multi-level car parks provide lower building cost per parking slot, as they typically require less building volume and less ground area than a conventional facility with the same capacity.
Considering all these fallibilities, we propound a system of parking within a parking area of 0.542m2 which not only has the parking cell detection system but also the 180-degree rotating ability and screw lifting.

3. Methodology

This section consists of the overall description of the hardware of the Automated Car Parking system and details of the circuit used in the project. It also discusses the step by step development of this research works.

3.1 Lead Screw Method:

Lead screws use the helix angle of the thread to convert rotary motion to linear motion. This is one kind screw uplifting method through the shaft of the actuator. This is familiar with the conventional Archimedes' screw method presented in **Fig.1**, The Archimedes screw consists of a screw (a helical surface surrounding a central cylindrical shaft) inside a hollow pipe. The screw is usually turned by a windmill, manual labor, cattle, or by modern means, such as a motor. As the shaft turns the bottom end scoops up a volume of water. This water is then pushed up the tube by the rotating helicoid until it pours out from the top of the tube. We experiment the lifting up through various method but we find the precise result in this lead screw system.

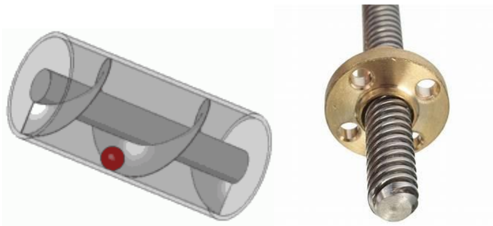
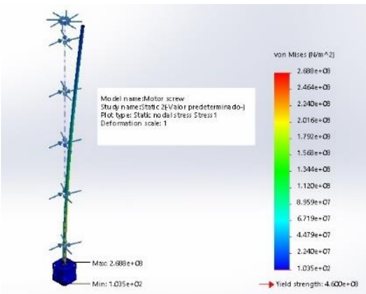


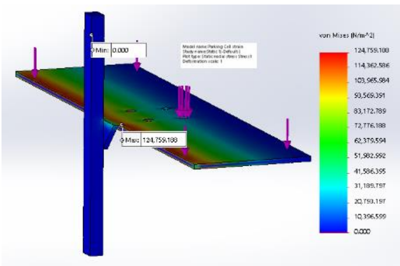
Fig. 1. Archimedes' screw method and Lead Screw method

3.2 Simulation:

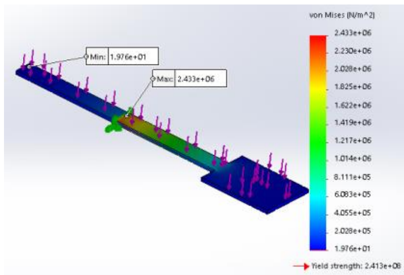
a) Von Mises stress analysis: To finding the capitulated criteria of identical or tensile materials under composite load Von Mises stress analysis is used. According to Von Mises yield criterion, it is independent of first stress invariant. When the second deflected stress invariant will reach a scathing value, the tensile materials will exceed capitulated point. The stress analysis of our lead screw stress due to torque, parking cell stress, vehicle grabber stress, motor strain due load are given in **Fig.2**, I, ii, iii and iv respectively. We used cast Stainless Steel for parking cell, AISI 4130 steel for beam, lead screw and other supports.



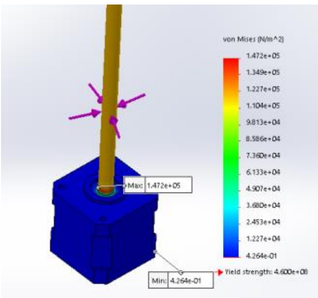
i) Lead Screw Stress due to torque



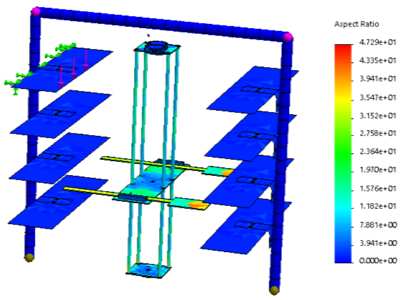
ii) Parking Cell Stress (5N)



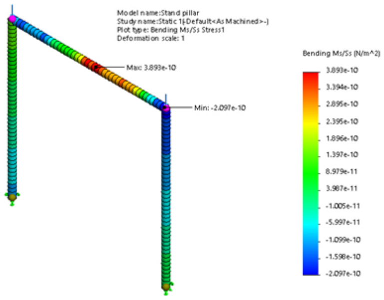
iii) Vehicle grabber stress (2N)



iv) Motor strain due to load (6N)



v) Aspect ratio of system

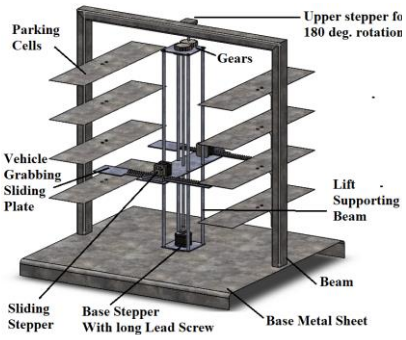


vi) Beam bending stress(20N)

Fig. 2. Various kinds of simulation result based on load, torque stress (Design ratio 4000:1).

b) Aspect ratio check plot: The proportion between the longest perverted edge and the concise normal descend from a peak to the contrary face normalized concerning an accurate tetrahedral is known as Aspect Ratio From the definition it is clear that the aspect ratio of a perfect tetrahedral element is 1.0. It measures simulated straight edges joining the four corner node. Generally, a car vehicle weight varies from 1300-1900N. Here we assumed 2000N for each car and our design ratio is 4000:1. In **Fig.2 (no. v)** is the mesh aspect ratio of our system.
In **Fig.2 (no. vi)** beam bending result has been shown which was simulated for 20N load each beam.

3.3 Hardware:



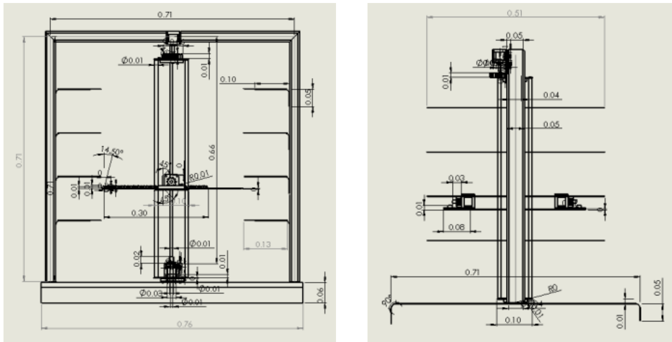


Fig. 3. Complete System Assembly **Fig. 4.** Drawing of front and side view (MKS Unit system)

a) Design Procedure: In this paper, we designed a prototype and its model done by Solidworks design software. Here the challenging issue is to make it space-efficient. So a central shaft is used for car lifting purpose and this way consumes less space. Then we designed the multilevel car parking spaces shown in [Fig. 3.]. The central shaft has a car holder space and it's important to maintain a minimum clearance between car holder spaces to parking space. The main lifting platform and car parking slots are holds by a frame shape structure shown in side view in **Fig. 4.** After that, we designed all those design components that are shown in figure 3. Though our design is a prototype that's why we scaled it down and overall well-equipped assembly shown in figure 4. In most of the parking, the system used a fixed plate transferring system. In our system, we designed sliding plates transferring system and in this method, two parallel plates slide simultaneously to maintain a balance car shifting process which is needed for transferring a car to the desired parking position. This sliding technique is effective for less volume of space. We designed every single part like base metal sheet, Leadscrew, Rack-pinion, beam, Gears, stepper motor in SolidWorks. After that, we assembled those presented in **Fig. 3**. After finishing the model we went to the Machine Shop to make the weldment and sheet metal works.

b) Components Assembly

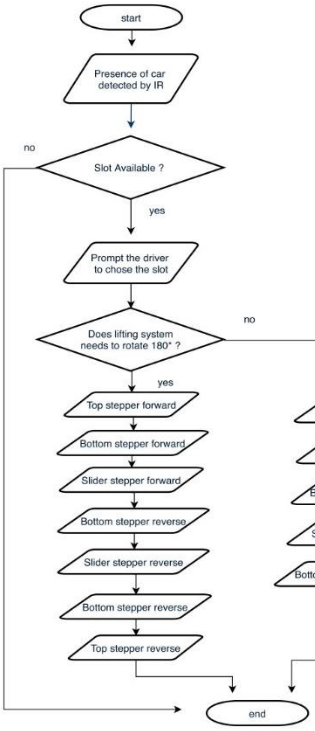
i) Lead Screw Lifting: Our lead screw was in 0.66m(26 inch) in height and diameter was 0.025m(1 inch). We made a baseplate welding a hexagonal screw and fix it with the lead screw. We noticed that screw doesn't swift properly for heavy load. Then we add four supporting rods with baseplate and fix the alignment in between lead screw and the baseplate. At last, we joint this lead screw with the shaft of NEMA 23 stepper motor. We also made proper housing for the safety of the motor.

ii) **Beam and Parking Cell:** For our toy cars which were in length of 0.1524m(6 inches) and width of 0.1016m(4 inches) we made the housing plate in length of 0.3556m(14 inches) and width of 0.127m(5 inches). Total eight number of housing plate has been installed with the beam.

iii) **Vehicle grabbing plate with gear-rack mechanism:** The vehicle grabbing plate has been designed as the rack-gear mechanism. This grabbing plate was installed with both moving stepper motors which attached with the up and down lead screw base. We make the gear and rack through lathe machine and fixed those with some bush and rollers for better alignment.

iv) **Beam and Parking Cell:** Another stepper motor Nema-17 has been attached on the top middle of the beam. A gear diameter of 0.0508m(2 inches) fixed with the shaft of the motor and another gear is coupled with this one. The second gear holds the total screw base system and also can rotate for the desired direction.

3.4 Algorithm:



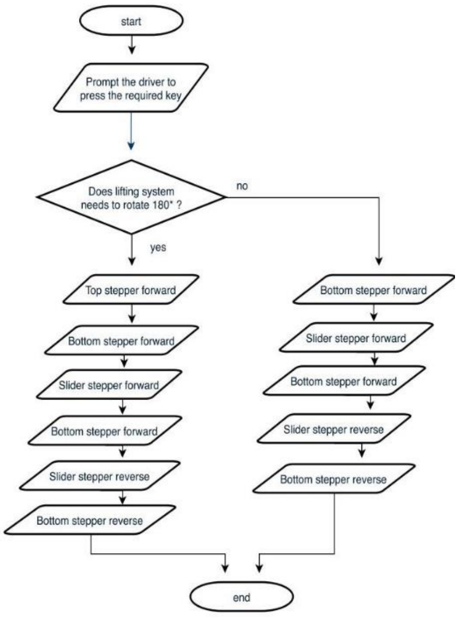


Fig. 5. Algorithm of parking Car **Fig. 6.** Algorithm of retrieving Car

IR sensor exists under the cells sense the presence of vehicles and shows the LED board which cells are available. When the client press the required key, top stepper, bottom stepper, and slider stepper runs forward-reverse precisely shown in flow chart **Fig. 5.** Again for the receiving command its follow the logic shown in **Fig.6.**

3.5 Schematic Diagram:

The control circuit consists of four TB6560 motor driver running through the command for required parking cell from the keypad shown in **Fig.7.** All the functions are processing through the Arduino Mega microcontrollers input and output pins. Four Nema series stepper motor has been used as an actuator and a 24v DC SMPS was used for the power supply unit.

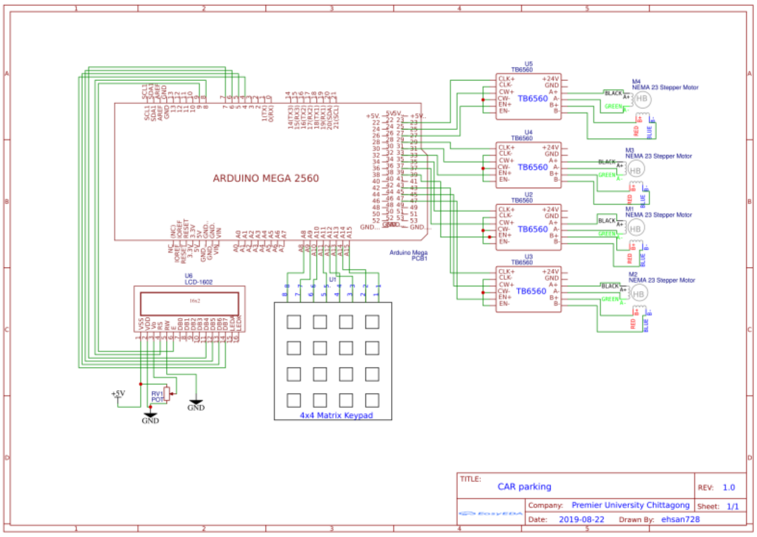
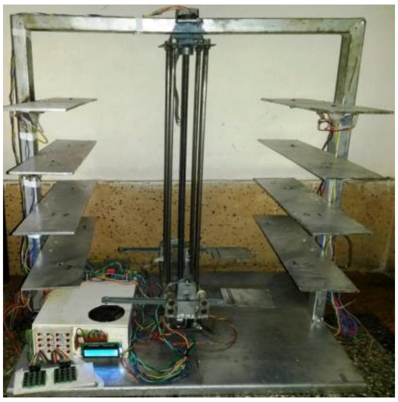


Fig. 7. Schematic diagram

4. Implementation



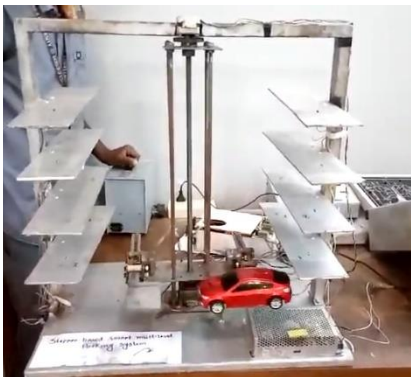


Fig.8. Final implementation with control unit **Fig.9.** Final implementation of working

Our designed prototype parking system was successfully able to parking and getting all 16th cells two cars on each floor shown in **Fig.8** and **Fig.9**.

4.1 Practical Implementation overview

Requirements of various multilevel parking, capacity and size, retrieval time and cost of operation has been shown in **Table 1**, **Table 2**, **Table 3**, **Table 4** respectively.

Table 1. *REQUIREMENTS OF DIFFERENT MULTILEVEL PARKING*

Car park type	***Continuous Power supply***	***Protection for externals***	***Entry & Exit point***	***Collection System***
Semi Autonomous	Medium	High	Single	Manual
Autonomous	High	High	Double	Unmanned

Table 2. CAPACITY AND SIZE OF DIFFERENT MULTILEVEL PARKING

Car Park Configuration	***Capacity***	***Dimensions***	***Number of Lifts***
Semi Autonomous elevator type	10 – 50 cars 50 cars in 45m^2 per unit or floor	Length: 5200 mm Width : 2250 mm Height: 2000 mm Weight : 2200 kg	Rail for Elevator
Autonomous Lead screw type	16-32 cars 4 cars, 25m2 (per floor)	Length: 5050 mm Width : 2040 mm Height : 1550mm Weight : 1850 kg	Central lift

Table 3. *RETRIEVAL TIME FOR DIFFERENT MULTILEVEL PARKING*

Car Park Configuration	***Capacity***	***Retrieval Time***	***Number of Entry /Exit Bays***
Semi Autonomous elevator type	10 – 50 cars 50 cars in 45m^2 per unit or floor	30sec ~ 60sec	2 entry bay and 2 exit bay
Autonomous Lead screw type	16-32 cars 4 cars, 25m^2 (per floor)	60sec ~ 120sec	Only 2 entry and exit bay

Table 4. *COSTS OF MULTILEVEL PARKING TYPES*

Car park type	Costs for 40~50 multilevel car parking (Approx million BDT)				Cost per space	
	land	***Cons.***	***Soft.***	***Develop.***	***Const.***	***operatio n***
Semi Autonomus	12	7.5	0.4	20	32,000	395 (per month)
Autonomus	12	15	0.7	28	20,000	265 (per month)

5. Conclusion and future works

Successful implementation of this project would result in less traffic and chaos in crowded parking spaces like malls and business buildings where many people share a parking area. The automated parking fee system would allow people to travel without cash. It provides drivers with Also, as it would reduce the waiting time, long queues, tension, stress and increase the efficiency of the parking system. As the Smart Car Parking System Requires minimal manpower, there are minimum chances for human errors, increased security in addition to a swift and friendly car parking experience for drivers.

Some future scopes of this project are:

- PID based error detection.
- RFID based input.
- IoT based Billing system
- GSM and WiFi-based billing system.
- Human Machine Interface (HMI) control system
- Programmable logic controller (PLC) based control system.

6. Acknowledgment

At the very beginning, we proclaim that we are grateful to the almighty and the most beneficent, for enabling us to complete the project work. We are very heartful to the mechanic Uttam Barua for helping us in weldment and machine shop works.

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