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Design of an Accessible Door System in High Floor Buses for Wheel Chair Users

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ABSTRACT
A large portion of the physically disabled community of the world is currently using wheel chairs which is not universally accessible. In many countries, public transport system depends on high floor bus and a wheel chair user fails to access to that comfortably. This research aims to demolish that problem of inaccessibility through a modification of the high floor bus door. The basic methodology here, consists of movable door-step system (one vertically and other horizontally) which allows the lifting of a wheel chair into the bus. Two linear actuators and two rack and pinion mechanisms are involved in this system. In this research, through simulation analysis the feasibility of the lifting step is tested. Eventually, the cost is discussed for performing this type of modification in a public bus in Bangladesh. So, this work will help people to find an effective mean to make public buses accessible for disabled persons.

KEYWORDS: Universally accessible, linear actuator, rack and pinion mechanism, Simulation analysis

1.0 Introduction
Almost 7 percent of the world population belongs to physically disabled society. Most of them use wheel chairs for overcoming accessibility boundary. Yet, wheel chairs are not universally accessible and in countries like Bangladesh all public buses are high floor and a disabled person faces major difficulty if he wants to travel by bus like a privileged person. In countries like USA by dint of ADA act (Americans with Disabilities Act of 1990) the public transportation system are habituated with modified bus with low floor and modified door. Moreover for the safety conditions inside the bus WTORS (wheelchair tie down and occupant restraint system) is adapted for rendering comfort for a physically disabled personnel. [1] But, in countries like Bangladesh there is no low floor bus system. Yet, a lot of people here are dependent on wheelchair and currently unable to move long distance because of the lack of facility of access and safety in the public bus. This research work aims to make a mean for allowing the wheel chair users to enter comfortably into the public bus. In the first phase of this paper, the model of such a door system is provided. And then, in the second phase, a modification in the interior of the bus is rendered following WTORS system. [1] Finally the simulation of wheel chair lifting plate is analyzed and cost for such a modification to currently available bus system is discussed. The control loop of the program algorithm and the electric circuit diagram needed for these modifications are also provided with this research paper. For simulation analysis the CAD platform of solid works is used which is very popular in recent years and Vivek kaundal also used this platform for design and simulation in his research work in 2012. [2]

2.0 Background research
It is an old demand of people to provide facility to the one who is not physically privileged. Research has been accomplished in 20th century and in the United States, all new mass transit vehicles placed into service after July 1, 1993 became accessible to persons in wheelchairs [3] and until the 2000s, this requirement was most commonly met by the inclusion of a wheelchair lift. Low-floor transit vehicles (buses, streetcars, light rail cars) – fitted with ramps or bridge plates rather than lifts – later began to become more common than lifts for heavy-duty transit vehicles, while lifts continued to be used in para-transit vehicles. [4] Currently in few low floor buses there is a cross arm mechanism present which is used for lifting the wheel chair up to bus interior. But none of these systems can

Fig.1 A wheelchair lift in the front door of a low floor city bus in San Francisco

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be implemented for high floor buses as there is about 15 inch distance between the ground and lower base of a traditional bus door. So a reasonable lifting mechanism is needed to be taken place which is the main motto of our research work. By field inspection in CRP (Centre for rehabilitations of the Paralyzed), Savar, Bangladesh the real scenario regarding this matter was readily understood. CRP made a mean for shifting disabled patients with wheel chairs into one of their buses using a 50 inch inclined surface. But that requires a long free distance in road which is most of the time unavailable in jam pact cities like Dhaka. So, a better solution is now needed to take into account.

3. Design of the model

In Bangladesh, BRTC (Bangladesh Road Transport Corporation) buses are most available. So, the system is designed based on the structure of a BRTC bus. In general, BRTC buses have 2 doors, one in front side closer to driver and the other at the middle. Here the

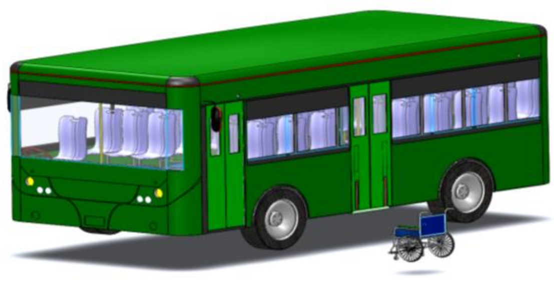

Fig.2.1 Bus comes at stoppage

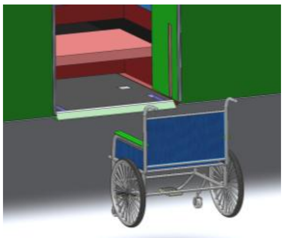

Fig.2.2 Door opens

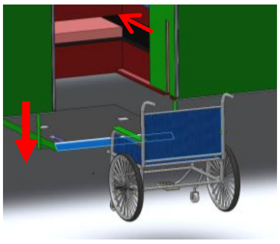

Fig.2.3 Step comes down

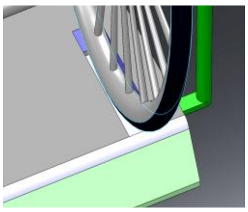

Fig.2.4 Chair gets in

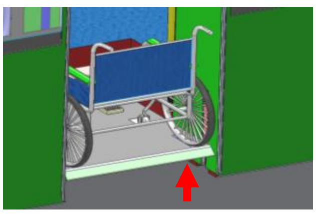

Fig.2.5 Step moves up

design is done for the middle door. The mechanical model of the door system was prepared and simulated using solid works CAD platform. We are going to describe the system in two phases.

3.1 First phase

The Door system and the methodology of lifting:

As we stated earlier, our lifting system consists of 2 movable steps (fig.2) instead of two fixed conventional steps of public bus. Among the steps one is vertically movable (first step plate fig.3) and the other is horizontally movable (second step plate fig. 4). The first step plate of the bus door can move vertically from the ground to the height of the base of the bus using two linear actuators. When the doors are open, (Fig.2) this vertically movable step can be moved using the actuator by pressing a switch. For free movement of the actuator the door is modified by cutting a portion (fig.5). This open portion is protected with a small plate that has rollers in two sides. So, when actuator moves up, this portion also moves up, when actuator moves down, this plate also moves down vertically dew to gravitational force inside the hollow portion of the door. And the plate attached to the actuator is made inclined at an angle of 45 degree at the forward edge for the ease of wheel chair driving into it. The 2nd step can come out and go hidden under the base of the bus using a rack and pinion mechanism. So, when a wheel chair user comes in front of the bus, the linear actuator will be turned on by the help of a switch and the vertical plate attached to it will go down. In the meantime the 2nd step will go hidden under the bus basement using the motor controlled rack and pinion mechanism.

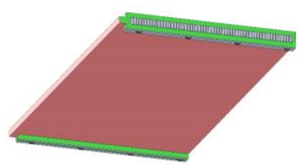

Fig.3 Horizontally movable plate with roller and rack slots

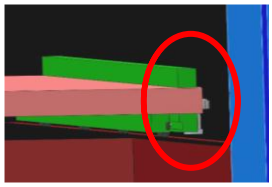

Fig.4 Horizontally movable plate installed in the bus connected to pinion gear

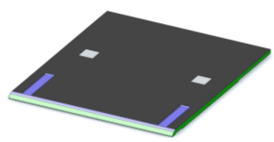

Fig.5 Vertically movable plate with 4 slots for the placement of 4 wheels

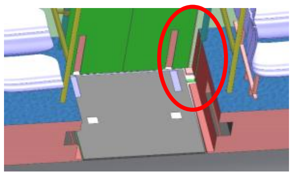

Fig.6 Vertically movable plate installed in the bus door connected to linear actuators.

Initially after the plate comes down, a wheel chair user can go up to the plate and fix the wheels at the modified cut surface (fig.3) so that the wheels don't roll during lifting. Secondly, when the wheel-chair load is charged on the plate, load sensor will guide the actuator for the lifting of the 1st step plate. When this plate comes at the interior base height of the bus, the actuator will be stopped and the user will comfortably go inside and take his position to a separated modified interior portion (fig.7) and fix his chair with the support of belts. Finally, after the wheel chair user has gone inside, the load sensor will guide the system and the doorsteps will get rearranged for the normal condition, for the general passengers.

3.2 Second phase
Interior portion modification:
The bus has a separate portion close to the door at the middle of the bus where there is an empty space for the placement of the wheel chair (fig.7). A wheel chair user will set his chair there and tie it with safety belts. The belt mentioned here is designed following WTOR System (fig.8); highly popular in the USA. This system prevents the wheel chair from rolling inside a vehicle during jerk or sudden break.

4. Terminologies used in description

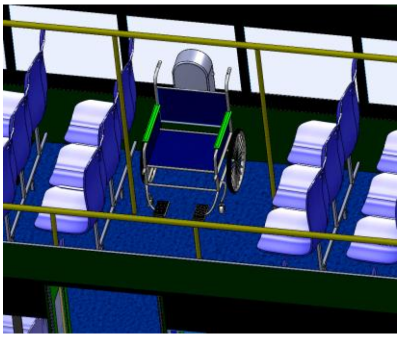

Fig.7 Modified interior portion of the bus for a wheel chair supported with the WTROS system

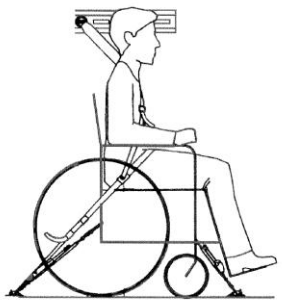

Fig.8 A typical wheelchair tie down and occupant restraint system (WTORS).

4.1 Universally accessible
This term refers the ability to access anywhere as per demand. The wheel chairs used now-a-days in Indian sub-continent are not of that type. Most of the times it is manually operated and travelling a long distance becomes impossible using such a wheel chair. That's why we are proposing the design to be implemented in the bus to help the disabled persons to make a way out to travel a long distance.

4.2 Movable step system
Movable step system (fig.2) means the two plates of our door system are movable linearly. The vertically movable plate is attached to the actuators which can move vertically at a range of 35 inches (15 inches lower and 20 inches upper than the normal lower step of the bus. The other plate has two threaded surfaces which will be used as rack and a motor controlled pinion gear is installed beside it to guide it to ensure linear movement horizontally.

4.3 Rack and pinion mechanism
A rack and pinion is a type of linear actuator that comprises a pair of gears which convert rotational motion into linear motion. A circular gear called "the pinion" engages teeth on a linear "gear" bar called "the rack"; rotational motion applied to the pinion causes the rack to move, thereby translating the rotational motion of the pinion into the linear motion of the rack

4.4 Linear Actuator
An actuator is something that converts energy into motion. It also can be used to apply a force. An actuator typically is a mechanical device that takes energy usually that is created by air, electricity or liquid and converts it into some kind of motion. That motion can be in virtually any form, such as blocking, clamping or ejecting. Actuators typically are used in manufacturing

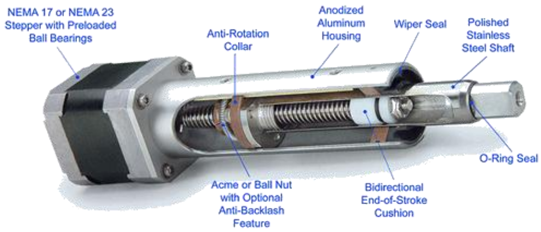

Fig.9 Linear Actuator

or industrial applications and might be used in devices such as motors, pumps, switches and valves. In our study, we used linear hydraulic actuator that is able to generate great power.

4.5 Load Sensor
A Load Sensor is defined as a transducer that converts an electrical output signal. Load Sensors are also commonly known as Load Transducers or Load Cells.

Fig.10 Load Sensor

4.6 Arduino board
For controlling the system, an Arduino MEGA board is used. Arduino is a single-board microcontroller, intended to make the application of interactive objects or environments more accessible. The hardware consists of an open-source hardware board designed around an Atmega 2650 microcontroller. Current models feature a USB interface, 6 analog input pins, as well as 14 digital I/O pins which allow the user to attach various extension boards.

4.7 Wheelchair Tie Down and Occupant Restraint System (WTORS):
The Society of Automotive Engineers (SAE) Recommended Practices J2249, provides best practice guidelines for the design, testing and performance requirements for WTORS. SAE J2249 states that a person seated in a wheelchair, should utilize both a wheelchair tie down device (e.g. docking, four-point strap), designed to secure the wheelchair in a forward facing position; in conjunction with an occupant restraint that consists of both a pelvic and upper torso belt, anchored directly to the vehicle or to the components of the wheelchair tie down device. [4]

5. Electrical Circuit:

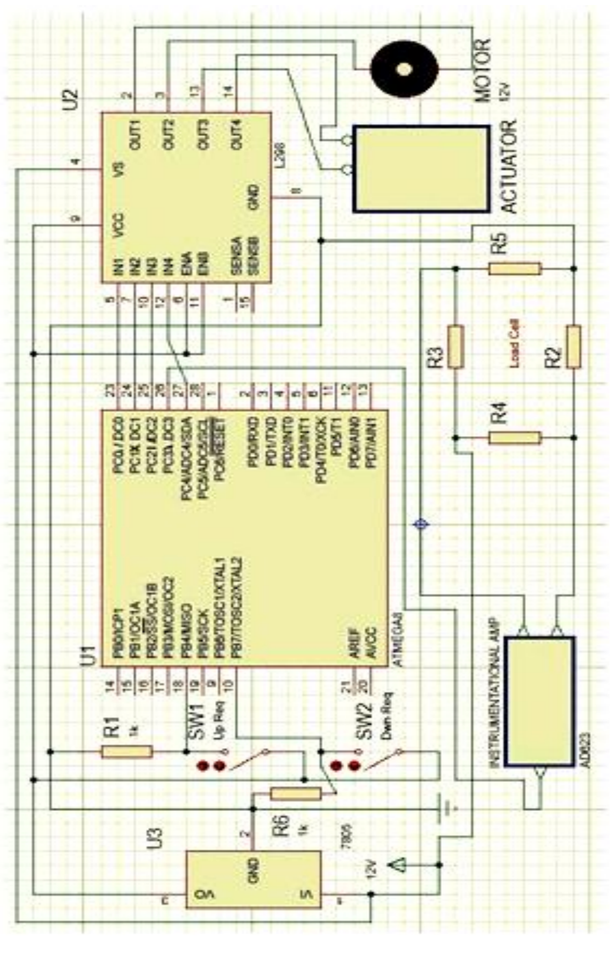

Fig.11: control circuit

In actual design 2 actuators and 2 motors are used. As they are identical only one connection is shown in figure.11 In real circuit another actuator and another motor should be added parallel to other actuator and other motor.

6. Program Algorithm (Control loop)
In order to perform the automation commands successively, a coded instruction should be provided via program algorithm which will act as the control loop. Here, the attached algorithm satisfied this purpose.

If (Up_Req PIN = HIGH)
    Rotate motor clockwise to limit (Sliding stair inward)
    Pull down the vertical stair to limit
    If (Load cell value > Threshold)
        Wait (5 sec.)
        Pull up the vertical stair to limit
        Wait (while (Load cell value > Threshold))
        Wait (5 sec.)
        Lower the vertical stair to the original position
        Rotate motor clockwise to limit (Sliding stair outward)

If (Down_Req PIN = HIGH)
    Rotate motor clockwise to limit (Sliding stair inward)
    Pull up the vertical stair to limit
    If (Load cell value > Threshold)
        Wait (5 sec.)
        Pull down the vertical stair to limit
        Wait (while (Load cell value > Threshold))
        Wait (5 sec.)
        Pull up the vertical stair to the original position
        Rotate motor clockwise to limit (Sliding stair outward)

7. Simulation Analysis:
Material used is Aluminum that is usually preferred for door step construction of a bus Dew to reliability and strength. We used here Aluminum 6063 T-6 alloy. The simulation was done in Solid works 2010 CAD platform. Firstly, the plate was divided into meshes and then Von Mises stress, Equivalent Strain, Expected displacement and factor of safety of the wheel chair lifting plate were studies.

Table.1: Plate information

Sr.	Part	material	Mass(kg)
1.	Vertical plate	Al 6063 T-5	64.69 kg

Table.2: Properties of Aluminium 6063 T-6 alloy:

Sr.	Properties	magnitude	unit
1.	Elastic Modulus	6.9 x 10^10	N/m^2
2.	Poisson’s Ratio	0.33	N/A
3.	Shear Modulus	2.58 x 10^10	N/m^2
4.	Density	2700	kg/m^3
6.	Tensile Strength	185000000	N/m^2
7.	Yield Strength	145000000	/K

7.1 Simulated Outputs:

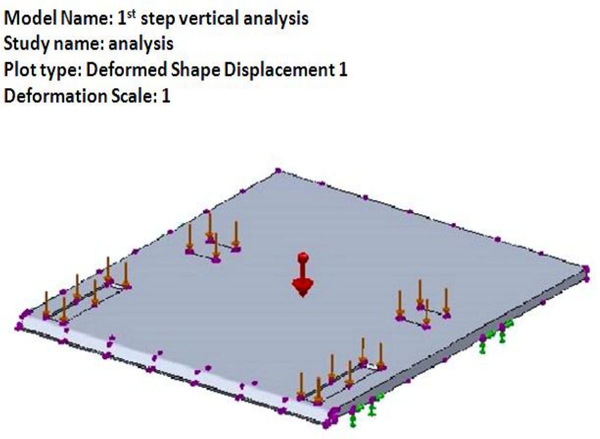

Fig.12 Mesh Diagram of vertically movable plate dew to wheel chair load

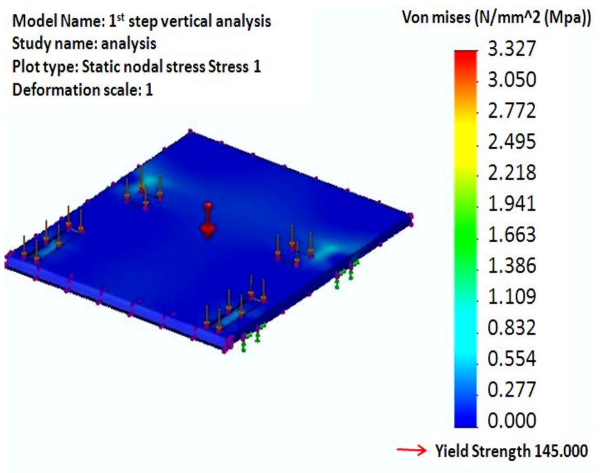

Fig.13 Von Mises Stress Analysis

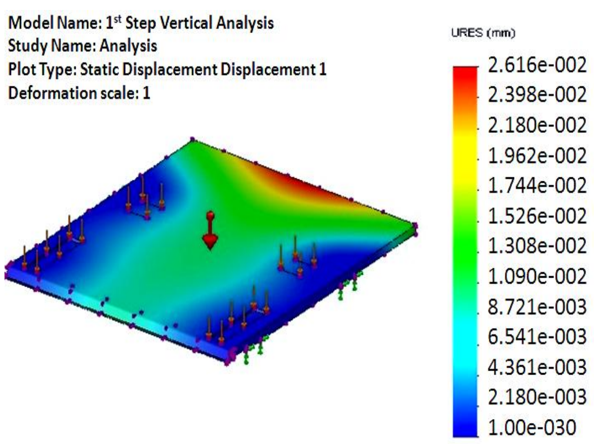

Fig. 14 Resultant Displacement (mm)

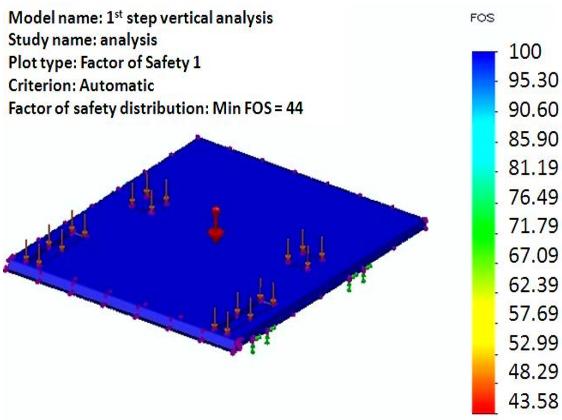

Fig.15 Factor of Safety at different positions of the plate

Table.3 Mesh Information

Mesh Type:	Solid Mesh
Mesher Used:	Standard mesh
Automatic Transition:	Off
Jacobean Check:	4 Points
Element Size:	0.82304 in
Tolerance:	0.041152 in
Quality:	High
Number of elements:	124745
Number of nodes:	204335
Time to complete mesh(hh;mm;ss):	00:00:24
Computer name:	mhrsazal

8. Terminologies used in simulation

8.1 Meshing

The partial differential equations that govern fluid flow and heat transfer are not usually amenable to analytical solutions, except for very simple cases. Therefore, in order to analyze fluid flows, flow domains are split into smaller subdomains (made up of geometric primitives like hexahedra and tetrahedral in 3D and quadrilaterals and triangles in 2D). The governing equations are then discretized and solved inside each of these subdomains. Typically, one of three methods is used to solve the approximate version of the system of equations: finite volumes, finite elements, or finite differences. Care must be taken to ensure proper continuity of solution across the common interfaces between two subdomains, so that the approximate solutions inside various portions can be put together to give a complete picture of fluid flow in the entire domain. The subdomains are often called elements or cells, and the collection of all elements or cells is called a mesh or grid. The origin of the term mesh (or grid) goes back to early days of CFD when most analyses were 2D in nature. For 2D analyses, a domain split into elements resembles a wire mesh, hence the name [2].

8.2 Von Mises Stress

The von Mises yield criterion suggests that the yielding of materials begins when the second deviatory stress invariant J2 reaches a critical value. For this reason, it is sometimes called the J2-*plasticity* or J2 flow theory. It is part of a plasticity theory that applies best to ductile materials, such as metals. Prior to yield, material response is assumed to be elastic.

8.3 Factor of Safety (FOS)

For structural applications FOS is the ratio of the allowable working unit stress, allowable stress or working stress. The term was originated for determining allowable stress. The ultimate strength of a given material divided by an arbitrary factor of safety, dependent on material and the use to which it is to be put, these gives the allowable stress.[5]

$$\mathbf{FS} = \frac{S_{\mathrm{al}}}{\sigma_{\mathrm{ap}}}$$

Where,

S_{al} = Allowable strength

σ_{ap} = Applied stress (Allowable stress)

FS = Factor of Safety

9. Cost analysis

Sr. no	Name of parts	Price /piece (BDT)	Number needed	Price (BDT)
1	Linear actuator	5000	2	10000
2	DC motor	300	2	600
3	WTROS system	4000	1	4000
4	Miscellaneous	2000	-	2000
				Total: 16600

10. Results and discussion

Through mesh analysis the stability of the model is readily understood as the maximum displacement for the material plate dew to the loading of a wheel chair with its user is less than a millimeter and the maximum stress is developed at four positions where wheels are touching the vertically movable plate and the stress is not acting at any alarming magnitude. The minimum factor of safety in mesh analysis comes as 43 which is more than enough for the stability condition.

The cost that is obtained is very reasonable and if government takes this project into concern for the sake of the physically disabled community of Bangladesh the cost can be further reduced.

Here, in this research work, we integrated the mechanical design, electrical circuit and program algorithm of the system which allows us to lift a wheel chair user comfortably into the high floor bus. Here there are still scopes of developing this system, the lifting system and materials can be modified by further research in this field. Through mesh analysis the stability of the model is readily understood as the maximum displacement for the material plate dew to the loading of a wheel chair with its user is less than a millimeter and the maximum stress is developed at four positions where wheels are touching the vertically movable plate and the stress is not acting at any alarming magnitude. The minimum factor of safety in mesh analysis comes as 43 which is more than enough for the stability condition.

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11. Conclusion

Accessibility is the first need of a person to communicate and to keep pace with the world. But here in Bangladesh dew to having no mechanism to transport a wheel-chair user in public bus, the accessibility to everywhere for a physically challenged person remains uncertain. This research has showed the current situation of bus system in countries like Bangladesh and stated a cheap way to come out from this situation by modifying the door system. It also created scopes of further research for developing this system for the noble sake of the wheel chair users.

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