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Conceptual Design and Analysis of Smart Steps for Elderly/Differently Abled Persons in Rural Public Transport Buses

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Abstract

The elderly and differently abled population in India is growing rapidly, posing challenges for accessing public transport due to inadequate infrastructure. Specifically, the first step height from the road level makes boarding and deboarding buses difficult, especially for elderly individuals with lower extremity impairments or arthritis. To address this issue, the authors designed and developed dynamic boarding and deboarding steps that would transport passengers from the road level to the bus floor. This article presents the design process, transient structural analysis, and fabrication of a scaled-down prototype made from acrylic material. Additionally, an electronic controller was incorporated to test the system's effectiveness before finalizing the design for real-time testing. The results indicated that the entire system met the functional requirements of dynamic smart steps. Furthermore, the article discusses the integration of nanotechnology and nanoscience in improving the system's efficiency and ensuring the safety of elderly passengers. By leveraging nanotechnology, the system's stability and durability can be significantly enhanced, providing a secure and reliable experience for vulnerable individuals. This research demonstrates a commitment to addressing the accessibility challenges faced by the elderly and differently abled population in India. By developing innovative solutions and incorporating advanced technologies like nanotechnology, the authors aim to create inclusive and improved public transportation systems and potential to positively impact the lives of numerous individuals by enabling them to access public transport with ease and confidence.

Keywords

Smart steps, Public buses, Elderly people, Transient analysis, Nanocoatings, Nanosensors

Introduction

In India, a large population of people and communities rely heavily on public transit; since it paves a convenient and cost-effective solution for individuals to travel around without relying on private vehicles [1]. Buses are one of the most economical types of public transit, making them especially appealing to individuals on a limited income [2, 3], they are not only providing a reliable mode of transportation, but they also assist to alleviate traffic congestion and air pollution in cities. As a result, public buses play a crucial role in ensuring that cities remain accessible and livable for all citizens [4]. However, access is not possible for everyone owing to physical or cognitive disabilities [5, 6], and a major barrier is the height of the first step of the bus from the ground level, making it more difficult for persons of certain age groups to board and deboard buses [5]. This is especially true for the elderly and individuals with physical disabilities [7, 8], as shown in figure 1.

Figure 1: Elderly women and people with lower extremities facing difficulty to board and deboard on a raised footboard [9-12].

Generally, the bus body manufacturers design the first step at a height of 300 - 400 mm above ground level to ensure that the vehicle is not damaged during transit [13], but this has become a significant barrier for the elderly and differently abled groups [14]. Taking all these factors into account and most of the developed and developing countries built differently abled-friendly buses with wheelchair ramps/lifts and kneeling/low floor buses [15-17]. India is the world's youngest country with 1.3 billion people and with 29 years being an average age. As a result, more attention has been paid to the younger generation in the construction of amenities and infrastructure is based on this bulge, as per the Economic Times [18]. But the concerning factor according to the Census 2011, there are about 104 million elderly persons aged sixty and above, accounting for 8.6 percent of the entire population, with females outnumbering males as per World Health Organization [19]. To ensure a better quality of life for the elderly, the government is undertaking various initiatives, but the transportation in public vehicles becomes much more difficult due to the increase of people's life expectancy, which has doubled since independence in India [20]. There are numerous areas in which the government is striving hard to improve amenities for the elderly and differently abled people in the country, for future-ready by introducing the low floor buses and wheelchair ramps/lifting systems in public buses plying in most of the metropolitan cities of India [21-23].

The advent of low floor buses with wheelchair lift/ramps are fairly ideal for metropolitan cities like Mumbai, Bangalore, Chennai, Delhi, etc., due to the well-maintained roadways [24], there are few chances of damage to the bus while in transit. However, the reality is that the lower-income individuals reside in rural areas where only high-floor public buses are provided due to the condition of roads and non-availability of kerbs at each bus stop, creating an inconvenient situation for the old and differently abled people who wish to participate equally with India's younger crowd [24].

In the context of India's reliance on public transportation, particularly for its elderly and differently-abled population, integrating nanotechnology and nanoscience stands as a transformative approach. The challenges faced by these individuals due to inaccessible bus infrastructure can be mitigated significantly through nanotechnological innovations. The bus steps can be manufactured using nanomaterials that are not only lightweight but remarkably strong, ensuring ease of movement without compromising durability [25]. Advanced nano-coatings enhance the steps wear resistance, protecting against corrosion and environmental damage, thereby ensuring long-term reliability [26]. Furthermore, nano-sensors, designed with precision, can be integrated into the steps. These sensors detect changes in pressure and weight distribution, allowing real-time adjustments in height and alignment [27] additionally, self-healing nanomaterials enable autonomous repair of minor damages, ensuring continuous structural integrity [28]. Nano-coatings can also provide anti-skid properties and have antibacterial capabilities, enhancing safety and hygiene for all passengers, especially those with specific health vulnerabilities [29]. This integration of nanotechnology into the design and fabrication of public transport systems not only enhances efficiency but, more importantly, ensures safety and accessibility for all passengers. By harnessing the potential of nanotechnology, public transportation in India can transition into a more inclusive and secure mode of travel for its diverse populace.

The authors attempted to focus this critical issue of the communities: public transportation accessibility and designed fully functional prototype of automatic dynamic smart steps system with an electronic controller and discussed in this article, in light of the challenges and lack of infrastructure amenities suited for elderly people with reduced mobility in public transportation buses of India.

Experimentation

Design of smart steps

The design of the smart steps started by taking the actual existing dimensions of steps of Tamil Nadu State Transport Corporation buses plying in the rural areas of Thondamuthur Taluk, Sadivayil Village, as shown in figure 2 and table 1. Solid Works 2022 software was used to model the assembly, designed to accommodate both ordinary and elderly people without taking up extra space. The mechanism consists of four steps (S_1 to S_4), with S_4 being the fixed bus floor. S_1 and S_2 have horizontal rectangular protrusions called spikes, which lift the other steps during virtual upward movement. Two 12V DC stepper motors connected to the lead screw mechanism drive the mechanism, lifting the steps from ground level to the bus floor level, as shown in figure 3. The first step is connected to the lead screw using an inverted L-shaped bracket with a nut

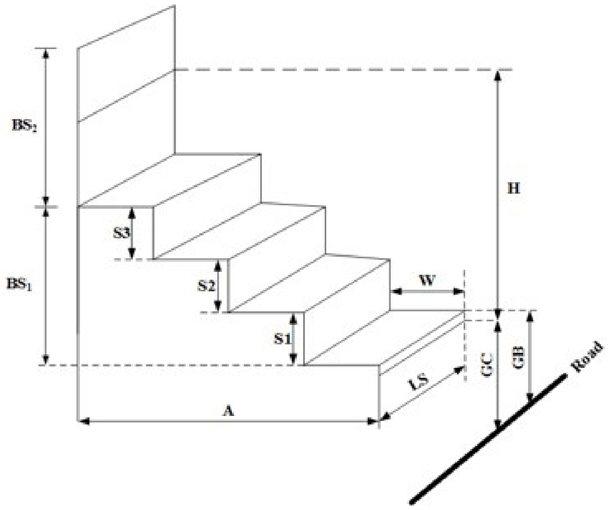

Figure 2: Existing dimensions of steps in local TNSTC buses.

Table 1: Dimensions of TNSTC rural bus.

S. No.	Description	Code	Normal bus (mm)	Deluxe bus (mm)
1	Length of Steps	LS	850	1080
2	Width of the steps	W	245	250
3	Height of the step 1, step 2, and step3	S_1, S_2 and S_3	215	240
4	Height from first step to the window base	H	1300	1350
5	Ground clearance (between the ground and the first step)	GC	410	355
6	Ground to the bus body base	GB	470	390
7	Bus base to bus floor height	BS_1	645	710
8	Bus floor to bus entrance post	BS_2	1375	1310
9	Distance between to vertical hand hold rods	A	570	725

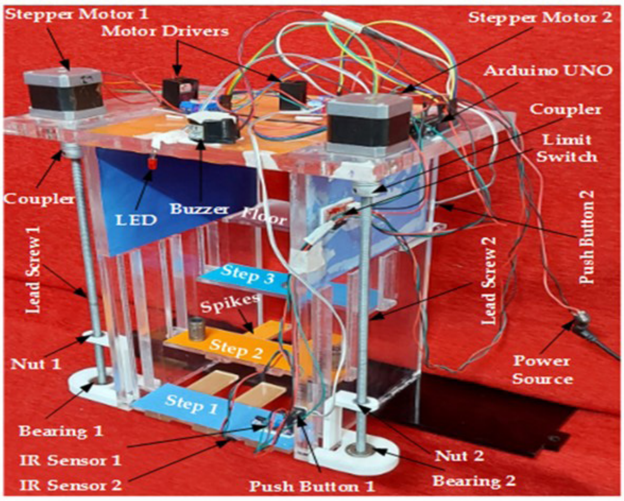

Figure 3: Prototype of smart steps with electronic controller.

that pulls the step up or down based on the motor's direction of rotation.

Algorithm for python IDLE

The design of a square threaded power screw is done using the Python IDLE (contact authors for code or (click for here for code) , which incorporates formulas from Shigley's Mechanical Engineering Design Book, 11th Edition and the input and output values are detailed in the table 2.

Input

Read the input parameters: major diameter (d), pitch (p), number of starts (n), load acting per screw (F), coefficient of friction between thread and nut (f), coefficient of collar friction (fc), mean collar diameter (dc), number of engaged threads (nt), Young's modulus of Screw (E), Length of the Screw (L), and Factor Safety for Buckling (FoS).

Output

Mean (pitch) diameter (dm), Root diameter or minor/core diameter (dr), Lead (l),Thread Depth (td), Thread Width (tw), Torque necessary to raise the load (Tr),Torque necessary to lower the load (Tl), Efficiency while lifting the load (η), Bearing area between screw and nut (Ba), Body shear stress (τ), Axial nominal normal stress (σ), Bearing stress (σB), The bending stress (σb), Normal Stress σx, σy, σz, Shear Stress τxy, τyz, the tangential shear stress (τzx),The von Mises Stress (σv), Buckling load (Pcr), and Safe Compressive load (Psc).

Table 2: Output results in the python compiler.

User inputs	Python IDLE compiler output	
1. d = 20 mm	a) It is a self-locking screw	m) σB = -12.73 Mpa
2. p = 2 mm	b) dm = 19.0 mm	n) σb = 40.32 Mpa
3. n = 2	c) dr = 18.0 mm	o) σx = 40.32 MPa
4. F = 2000N	d) l = 4.0 mm	p) σy = -7.86 MPa
5. f = 0.08	e) td = 1.0 mm	q) σz = 0 MPa
6. fc = 0.08	f) tw = 1.0 mm	r) τxy = 0 MPa
7. dc = 25 mm	g) Tr = 4808.29 N.mm	s) τyz = 4.19 MPa
8. nt = 1	h) Tl = 2245.44 N.mm	t) τzx = -4.41 MPa
9. E = 206000 MPa	i) η = 26.48 %	u) σv = 45.99 MPa
10. L= 1100 mm	j) Ba = 59.69 MPa	v) Pcr = 2164.62 N
11. FoS = 2	k) τ = 4.19 MPa	w) Psc = 1082.31 N
	l) σ = -7.85 MPa	

Upon the compilation of the code, the output values for a standard screw rod with major diameter of 20 mm and 2 mm pitch are considered safe for a maximum axial load of 2000 N as given in the table 2, which is concentrated at the mean diameter of the collar bearing. The use of a double start screw in this design, provides a self-locking feature, which prevents rotation under the axial load and only allows rotation when torque is applied from the motor. Additionally, the von Mises stress calculation yields a result of $\sigma v = 45.99$ MPa, therefore it is lower than the structural steel yield strength of 250 MPa, indicating that the design is safe.

Transient structural analysis of smart steps

The design model was completed with careful consideration given to all aspects of the design, including safety and material selection. To prepare for simulation, the design was converted to a data exchangeable format of ".IGES format". The transient structural analysis was conducted using Ansys Workbench version 2015. Prior to running the analysis, materials were assigned to each part of the assembly, and properties of each material were extracted from Ansys reports. The relevant information has been compiled in the table provided below as table 3. During the material selection process, since there is a high amount of wear between the square threaded power and nut. Therefore, a softer material was assigned for the nut, which is easier to replace the nut in comparison to the screw. This careful consideration of material selection is crucial in ensuring the longevity and effectiveness of the design.

The purpose of the analysis was to determine the deformations and stresses that occur when a person steps on the mechanism. A weight of 1000 N was assumed for the person, and a factor of safety of 5 was used in the design. The meshing was initially performed with default element size. Boundary conditions were then applied by uniformly distributing a load of 5000 N on the first step for the first four seconds, followed by three seconds on the second step and final three seconds on the last step. The deformations and stresses over a 10-second period with a time step of 0.5 sec were studied, as shown in figure 4b and figure 5b. The maximum deformation values on steps S_1, S_2, and S_3 were 0.92176 mm, 0.85788 mm, and 0.86908 mm, respectively, at time intervals of 1 sec, 5 sec, and 9 sec, as shown in figure 4a and these findings suggest that the design's deformation values are negligible, even under an applied load of 5000 N, which indicates that the design is safe and can withstand the load without any significant damage or failure. The graph depicted in figure 4 illustrates the deformations over a ten-second period, with a time step of 0.5 sec, providing a visual representation of the design's response to the applied load.

Stress analysis is also an important parameter to consider. The equivalent stress values on steps S_1, S_2, and S_3 were found to be 30.154 MPa, 20.814 MPa, and 21.238 MPa, respectively, at time intervals of 1 sec, 5 sec, and 9 sec, as shown in figure 5a. These values are well below the material's yield strength of 250 MPa, confirming that the design can withstand the applied load without significant stress-induced damage or failure. Figure 5b provides a visual representation of how the stresses change over a 10-second period with a time step of 0.5 sec, allowing for a better understanding of the design's response to the load. The design is safe, as both the deformation and stress values are below the safe limit. The analysis results provide confidence in the design's structural stability and confirm its safety and reliability for its intended purpose.

Buckling analysis

To ensure safe operation of a 20 x 2 mm metric square thread (fine) lead screw (IS 4694-1968), the critical buckling load was numerically analyzed by applying 1 N of axial load and multiplying it by the load multiplier. The maximum critical buckling load was found to be 1959.5 N, ensuring the lead screws load-bearing capacity and safe operation. The safe compressibility load (Pcs) was calculated as 979.6 N by dividing the maximum critical buckling load by a factor of

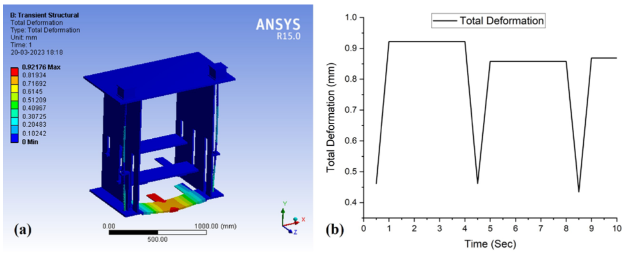

Figure 4: Total deformation of the steps S_1 S_2 and S_3 over the period of 10 sec.

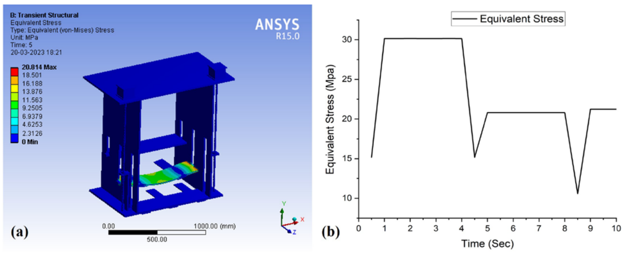

Figure 5: Equavalent stress of the steps S_1, S_2 and S_3 over the period of 10 sec.

Table 3: Properties of the materials used for analysis.

S. No.	Properties	Lead screw	Nut	Other Parts
1	Material	Steel structural	Bronze	Aluminum
2	Modulus of elasticity	206000 MPa	117000 MPa	71000 MPa
3	Poisson's ratio	0.33	0.34	0.33
4	Tensile ultimate strength	460 MPa	379 MPa	310 MPa
5	Tensile yield strength	250 MPa	165 MPa	280 MPa
6	Compressive yield strength	250 MPa	165 MPa	280 MPa

Table 4: Comparison of buckling analysis results.

S. No.	Type of analysis	Critical buckling load (Pcr)	Pcs with FoS of 2
1	Numerical	2164.6 N	1082.3 N
2	Workbench	1959.5 N	979.6 N

safety of 2, which guarantees that the lead screw can withstand twice the expected load without failure.

Table 4 presents a comparison between the buckling load values obtained from numerical calculations and Ansys workbench analysis. A discrepancy of approximately 200 N was observed between the two analyses, which was attributed to the assumption made in the numerical analysis that the rod was completely solid without threads.

Design of electronic controller

The electronic controller is designed using an open source, and the circuit is shown in figure 6. To reduce the human intervention to the maximum extent as much as possible, the system is equipped with infrared (IR) sensors and limit switches to detect the person on the footboards and operate the steps not exceeding the specified boundaries. The electronic controller designed is comprised of an Arduino UNO, two stepper motors, two motor drivers, two IR sensors, limit switches, two push buttons, a buzzer, and an LED light.

Operating principle

The controller was designed in such a way that it works for two cases, such as (i) when the elderly person wants to board the public bus, and (ii) When the elderly person wants to deboard the public bus.

While boarding the bus

When the elderly person wants to board the bus, he/she will press the push button 1 with an upward symbol which will be placed at a convenient height near the boarding area. Upon pressing the push button 1, the first step will give an alarming beep for five seconds then the First step moves down towards the road, until the signal from array of proximity sensors (here IR) sensor 2 which is fitted underneath the step to ensure the step will stop at 50 mm above the road level. Once it reaches the road level, the motor stops rotating, then the person can board on to the first step. Upon boarding the sensor fitted at the side of the step will get an obstruction, thereby sending signal to the controller to activate the motors. Before the motor starts it gives an alarming beep sound and after sending signal for five seconds the motor rotates anticlockwise then step 1 moves from the position P (-1) to the P (3) that's the floor of the bus. The spike underneath the steps helps to move the second and third step to the bus floor. Upon reaching the bus floor as shown in figure 7c, the system will wait for the person to move/walk inside the bus on the floor towards allotted seat. Once the Sensor detects no continuous flow of signal in the line of signal, the system will wait for the five seconds then again gives an alarming beep sound and controller sends the signals to motor to operate in opposite direction clockwise in order to go back to the position P (0). Now the steps will be static again, which can be used by the normal people as shown in the figure 7d.

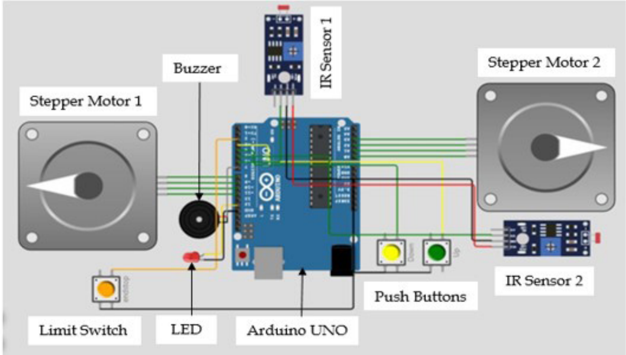

Figure 6: Circuit diagram of the electronic controller.

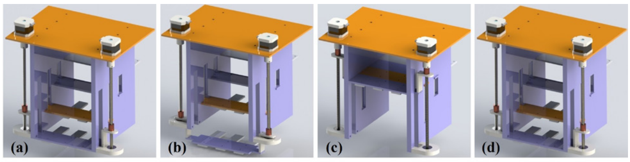

Figure 7: Position of steps while boarding and deboarding. **(a)** Step 1 at position P (0), **(b)** Step 1 at position P (-1), **(c)** Step 1, 2 and 3 at position P (3), and **(d)** Step 1 back to position P (0).

While deboarding the bus

When the elderly or differently abled person wants to deboard the bus, he/she needs to press the push button 2 placed near the deboarding area. Upon pressing the button, an alarming signal will be raised, after five seconds motor starts rotating in the anticlockwise direction then the first step will move from the position P (0) to the bus floor P (4) as shown in figure 7c. Now sensor 1 detects the person and waits for ten seconds, for the person to come and stand on the first step. Upon detecting an obstruction in the line of signal at first step sides, the system again plays a warning beep sound and starts moving the first step from position P (3) to the road level that's P (-1) as shown in figure 7a. The LED placed at the top entrance always lights up during the movement of steps. Once the person deboarded completely. The IR sensor 1 again waits for the obstruction in the line of signal, if it does not detect any obstruction in 5 sec again plays a beep sound and moves the step from position P (-1) to P (0) for allowing the normal passengers to board who doesn't require such assistance.

Results and Discussion

This paper presented a novel mechanism which is to be used initially in the rural going buses of Coimbatore district (Tamil Nadu, India). Where the people with limited mobility like elderly and differently-abled people to board and deboard the buses effectively without the help of others or without difficulty. The entire mechanical system is safely designed and conducted transient structural analysis in ANSYS Workbench 2015. The values were found to be safe under the sample load of 5000 N as the deformation is negligible and equivalent stress are well below the yield strength of the materials as detailed in table 5. Also, the system has some highlighted features namely (1) on non-usage, the steps will remain as the normal bus steps which will allow ordinary people to board/deboard

Table 5: Results obtained on performing transient analysis.

Time (sec)	Total deformation (mm)	Equivalent stress (MPa)	Maximum shear stress (MPa)	Factor of safety (FoS)	Tensile yield strength (MPa)		
					Steel structural	**Bronze**	**Aluminum**
1	0.92176	30.154	16.589	9.2856	250	165	280
2	0.9218	30.155	16.589	9.2854			
3	0.92179	30.154	16.589	9.2855			
4	0.92178	30.154	16.589	9.2855			
5	0.85788	20.814	11.841	13.453			
6	0.85796	20.815	11.841	13.452			
7	0.85796	20.814	11.841	13.452			
8	0.85795	20.814	11.841	13.452			
9	0.86908	21.238	12.084	13.184			
10	0.86912	21.238	12.085	13.184			

who doesn't require any assistance. (2) The system is designed to replace the existing steps with the dynamic intelligent steps which requires no extra space to be occupied. (3) Keeping in mind the stability issues which the scissor-based mechanism produces while motion, this system is designed in such a way that the steps only move vertically upwards and remain horizontally when reaching at all positions. (4) The system also has movement restrictions which act as a proper guide way and prevents turnover during boarding and deboarding.

Conclusion

It is concluded that certain areas require further attention, such as the vertical gap between steps and the need for a mechanism to accommodate wheelchair users. These aspects present opportunities for future innovation and refinement of the system. By incorporating advanced technologies like nanotechnology and nanoscience, the system's stability, durability, and safety can be further enhanced, ultimately creating inclusive and improved public transportation systems. The authors' commitment to developing innovative solutions has the potential to positively impact the lives of numerous individuals, enabling them to access public transport with ease and confidence. Further development and laboratory experiments will be conducted to refine the system and implement necessary adjustments based on feedback.

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Conflict of Interest

None.

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