

A multifunctional adjustable work desk using Arduino mega microcontroller and motors

Kyle Flanagan^{*}, Patricia Khwambala², and Kumeshan Reddy³

¹Nelson Mandela University, Department of Mechatronics, Gqeberha, South Africa

²Nelson Mandela University, Department of Mechatronics, Gqeberha, South Africa

³Nelson Mandela University, Department of Electrical Engineering, Gqeberha, South Africa

Abstract. The paper details the mechanical, electrical, and programming for designing and developing a multi-functional adjustable desk with automated height and tabletop tilting capabilities. The electrical system, featuring an Arduino Mega microcontroller, reads inputs from a control panel to control the linear actuators for height adjustment and a stepper motor for the unique tilting feature. Through rigorous testing, the desk achieved smooth, synchronised movements and reliable positioning at any height or angle. The work undertaken highlights the importance of motor control optimization. Additionally, the prototype achieved an error range of less than 1% for the zero-degree operation, and less than 1.5% for the ninety-degree operation. The developed desk is a high-quality, robust solution that integrates seamlessly into diverse working environments.

1 Introduction

Sedimentary behaviour has become a significant public health concern in contemporary society [1]. Given the increasing trend towards remote work and the growing emphasis on office ergonomics, the need for desks that can accommodate various working positions [2]. Research indicates that office workers are among the most sedentary groups, spending approximately 73% of their workday sitting down [3]. A crucial aspect that sets height adjustment desks (HADs) apart from traditional office desks is the height displacement they can achieve. Traditional office desks, however, offer no height adjustments of the surface, forcing the user to work in a sitting position.

Linear motion, also known as one-dimensional motion, is characterised by movement along a single spatial dimension [4]. The two ways this motion can be achieved is by using brushed DC motors or linear actuators. The use of a lead screw mechanism driven by a DC motor provides highly efficient linear movement, essential for adjustable desk applications [5]. The lead screw translates the rotational motion of the motor into linear displacement, ensuring smooth and accurate height adjustments. The lead screw's ability to handle significant loads and the stepper motor's high precision and low maintenance requirements

* Corresponding author: patricia.khwambala@mandela.ac.za

make this combination ideal for ergonomic applications. [6]. Ongoing research and development in actuators have led to enhanced control strategies and designs, resulting in their increased accuracy, durability, and energy efficiency [7]. Electromagnetic actuators transform electrical energy into mechanical motion. They are popular in the robotics industry because of their ability to operate with high efficiency, precision, and scalability [7].

Rotational control mechanisms in drafting tables provide a foundational comparison for enhancing the functionality of adjustable work desks. Traditionally, these tables feature a lever-locking mechanism below the tabletop, facilitating manual angular adjustments. The manual system, while functional, reveals a market gap for further automation and improvement. The application of solar panel tilting mechanisms provides an appropriate analogy. A control system for solar panels was showcased, which utilised 180-degree servo motors which dynamically adjusted the panel's positioning based on programmed algorithms [8]. The microcontroller could command the motors to rotate in both directions at varying speeds, modelling similar technology that could be applied to adjustable work desks. Controversially, stepper motors are used in precision control and positioning applications due to their step angles [9]. The review of rotational control mechanisms showcased the potential for adopting principles and applications from various sectors.

Actuators are frequently driven by software, with the control signal originating from a microcontroller [10]. A study [9] models the precise horizontal tilting of a solar panel, demonstrating the effective control of a stepper motor using an Arduino microcontroller. A software algorithm controls the angular rotation of the stepper motor with high precision, which is relevant to the adjustable work desk's screening feature. Moreover, the Arduino UNO efficiently handles tasks such as data reading, performing calculations, and managing control systems [9]. These applications highlight the microcontroller's capabilities of performing the operations of the adjustable work desk.

The paper evaluates the completed adjustable work desk, focusing on its design, construction, and performance testing. The following are the key contributions of the paper:

- A detailed mechanical, electrical, and programming design of the adjustable work desk
- An extensive explanation of the construction process
- Rigorous testing of the developed prototype

2 Problem analysis and system requirements

The following section addresses the need for a multi-functional, adjustable desk, while outlining the functional objectives and requirements.

2.1 Research rationale

The project aims to integrate engineering aspects to create a multifunctional adjustable desk. Utilizing both height and rotational control mechanisms, the desk can switch between a large range of working heights, and features tabletop rotation, allowing users to work at different angles. The research seeks to overcome the limitations traditional work desks, by creating a desk capable of reliable height adjustments and a full 90-degree tabletop tilt. This allows for sitting, standing, and specialised functions like presentation mode addressing the need for ergonomic solutions in modern workspaces.

2.2 System requirements

Table 1 summarises the top-level requirements that the system must fulfil.

Table 1. System requirements.

Requirement	Description
Sitting Mode	Provides a comfortable seated workspace
Standing Mode	Allows a transition to a standing position
Screening Mode	Tilts the tabletop to a 90-degree angle

To meet these requirements, specific design concepts were integrated to ensure functionality, ergonomics, and safety. The most suitable and feasible approach involved using actuators or a lead screw mechanism for height adjustment, coupled with a worm gearbox driven by a NEMA 23 stepper motor. The design choice effectively addressed all the research requirements.

2.3 Technical performance measures

The research requirements were carefully analysed to ensure that the desk met all necessary criteria. Table 2 outlines the TPMs for the desk, illustrating the importance of the factors considered during the design process.

Table 2. Technical performance measures.

TPM	Requirement	Importance
Height Adjustment	Automated height adjustment for both sitting and standing modes	20%
Screen Mode	Tilting tabletop from horizontal to vertical for versatile use	20%
Safety	Integrated locking, alarm, and sensors for user protection	15%
Load	Supports 70 kg seated, 30 kg s	10%
Stability	Ensures structural integrity under maximum load	10%
Surface	dimensions (1200 x 600 mm)	5%
Surface Finish	Whiteboard-compatible surface	5%
Mobility	Equipped with lockable castors	5%
User-Friendliness	Simple, intuitive control panel	5%
Minimalistic Design	Integrated components and uncluttered leg space	3%
Overall Appearance	Modern, black aesthetic	2%

3 Design description

The section outlines the development of the final adjustable desk design and details the reasoning behind specific design choices. A detailed description of the design process is

provided, including design specifications, relevant calculations, and graphical representations.

3.1 Description of the design development

The final design was developed to support two primary modes of operation: height adjustment and tabletop tilting. The mechanical, electrical and IT aspects of the final design are detailed below.

3.1.1 Mechanical aspects of the design

The desk structure is predominantly made from steel and aluminium to ensure stability and meet the "robust" design requirement. The Finite Element Analysis (FEA), illustrated in Fig. 1, shows that the horizontal legs experience the highest stress points, guiding the material choice and design.

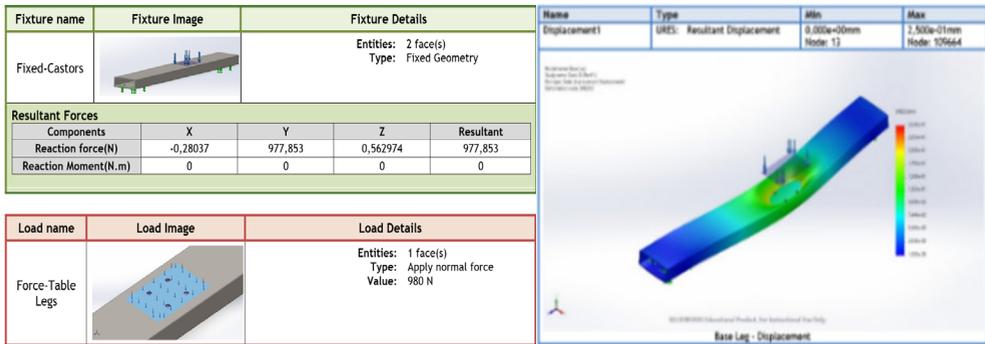


Fig. 1. FEA results on base legs.

The 1.6mm thick steel tubes proved adequate to support the maximum load. The telescopic legs relied on aluminium tubing that slotted into a channel and spacers. The setup, shown in , was chosen for its effectiveness in achieving smooth linear motion.



Fig. 2. Telescopic leg assembly.

The actuators in the above figure were mounted upside down, with the DC motor at the top of the legs to prevent cables from obstructing the linear motion. The arrangement also reduces the risk of injury, as the actuators face away from any moving parts during adjustments. The above image shows the actuator shaft exposed when the desk raises, creating a safety hazard. To solve this, a 3D-printed housing assembly shown below was used. The Guidelines for Driven Machinery Regulations of 2015 mentions that all shafts must be protected [11].

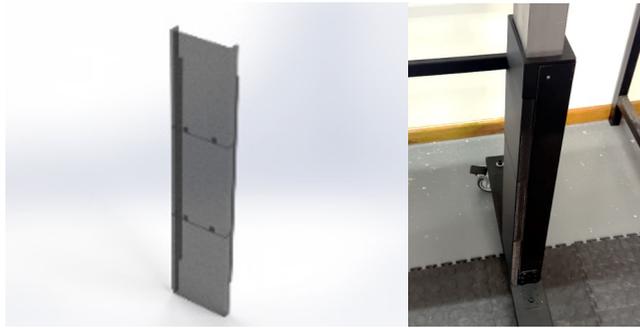


Fig. 3. Telescopic leg housing.

The housing depicted in figure 3 protected all moving parts and eliminated the risk of injury. The initial concept of using a single long shaft proved impractical for the tabletop's rotational mechanism due to alignment issues. A revised design, Fig. 4, utilised three shafts to tilt the surface. A flexible spider coupling links the gearbox output to the rotational arm, allowing minor misalignments between shafts.

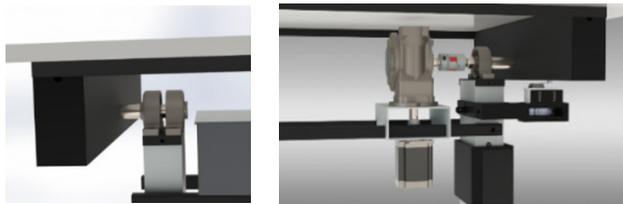


Fig. 4. Worm gearbox rotational system.

The rotating assembly has a total weight of 15 kg. Considering the width of the tabletop while neglecting friction and inertia:

$$T_{total} = T_{load} + T_{dynamic} \quad (1)$$

$$F = ma = (12)(9.81) = 117.72 \text{ N} \quad (2)$$

$$T_{load} = F \times d = (117.72) \left(\frac{0.6}{2} \right) = 35.16 \text{ Nm} \quad (3)$$

Considering the inertia of the desk surface when it stops and starts rotating, the dynamic torque needs to be calculated. The table rotates around the x-axis, and the centre of mass:

$$I_x = \frac{1}{12} ma^2 = \frac{(12)(0.6)^2}{12} = 0.36 \text{ kg} \cdot \text{m}^2 \quad (4)$$

The angular acceleration, the speed at which the surface will rotate, is required to calculate the dynamic torque. Rotational motion kinetic equation:

$$\Delta\theta = \omega_0 t + \frac{1}{2} \alpha t^2 \quad (5)$$

To achieve a rotation of 30° in 2 sec:

$$\alpha = \frac{2\Delta\theta}{t^2} = \frac{2\left(\frac{\pi}{6}\right)}{2^2} = 0.262 \text{ rad/sec}^2 \quad (6)$$

Therefore, the dynamic torque and total torque are as follows:

$$T_{dynamic} = I_x \cdot \alpha = 0.36 \cdot 0.262 = 0.622 \text{ Nm} \quad (7)$$

$$T_{total} = 35.16 + 0.622 = 35.78 \text{ Nm} \quad (8)$$

The above calculations indicate the output torque that the motor and gear system must produce to achieve the rotation of the surface. Together with the stepper motor, the rotational system produces a total output torque of:

$$T_{output} = T_{motor} \times T_{gearbox} = 1.26 \times 41 = 51.66 \text{ Nm} \quad (9)$$

The above calculation confirms the reliability of this rotational concept as it can produce approximately 15.88 Nm additional torque.

3.1.2 Electrical aspects of the design

The electrical system was designed to deliver stable power to the motors and ensure safe operations. Power is sourced from a 12V, 8.5A power supply, which steps down from the standard 230V AC to 12V DC, suitable for the linear actuators and stepper motor. The 3D-printed control box shown in figure 5 below housed all the electrical components of the desk.

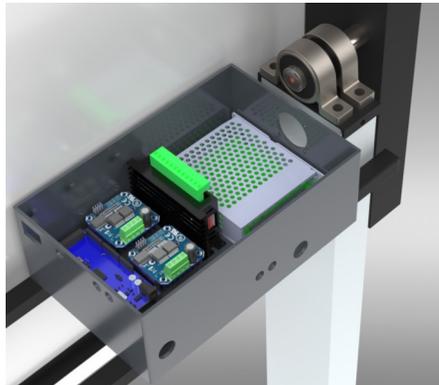


Fig. 5. Control box housing all electrical components.

An additional safety feature was an alarm system that notified the user of any mode changes. A piezo buzzer sounds if a motor is running, enhancing operational awareness and safety.

Fig. 6 illustrates the precise placement of the limit switches, which halt the motor as the tabletop approaches its endpoints at 0 degrees (horizontal) and 90 degrees (vertical). The arrangement was essential for maintaining the desk's safety standards by ensuring precise and repeatable stopping points. The accuracy and reliability of the limit switches were further validated through a repeatability test, the results of which are documented in the following section, "Performance Evaluation and Data Analysis."



Fig. 6. Limit switch trigger positions.

3.1.3 Software aspects of the design

The adjustable desk's control panel integrates four button functions: Raise, Lower, Tilt Forward, and Tilt Backward. Throughout the planning and design phases, several concepts for the rotational control system were evaluated, as illustrated in Fig. 7. Various tilting configurations were considered in consultation with project supervisors to provide the desired functionality for the screening mode.



Fig. 7. Rotating motion of screening mode.

Ultimately, momentary switches proved most effective as they allow the user to adjust the tilt continuously rather than being limited to set increments. Alternative designs with step increments of 15 or 30 degrees were discussed, which would have limited the tilting function to only a few pre-set positions, as shown in Fig. 7 above. The software code also includes logic to manage tilting limits using sensor feedback, preventing the tabletop from colliding with the desk frame while tilting.

3.2 Design specification and operation description

The following section provides a comprehensive specification of the final design of the built adjustable work desk in Fig. 8. The sitting and screening mode depicting the capabilities of the desk.



Fig. 8. Sitting and screening mode.

The complete design achieves structural stability, user control, and reliability in its intended functionalities. The following subsections detail the developed desk's mechanical, electrical, and software aspects.

3.2.1 Mechanical design description

The desk's mechanical design is engineered to ensure durability, stability, and precise functionality. The structure utilises robust materials to meet load-bearing requirements and support the desk's full range of motion. Fig. 9 shows the final leg assembly, emphasising the ball-bearing guide rails, which ensured balanced vertical motion and prevented lateral wobbling.



Fig. 9. Telescopic legs.

As illustrated above in figure 9, 3D-printed spacers and rails attached to each leg guided the inner leg to produce smooth height adjustments. The actuators are enclosed within the leg structure, providing a clean, uncluttered appearance. The rotational mechanism shown in Fig. 10 has a NEMA 23 stepper motor driving a worm gearbox. The motor, rated at 1.26 Nm torque, drives a worm gearbox with a 60:1 gear reduction to achieve a controlled tilt range from 0° to 90°. The figure below shows the spider coupling, allowing minor alignment adjustments.

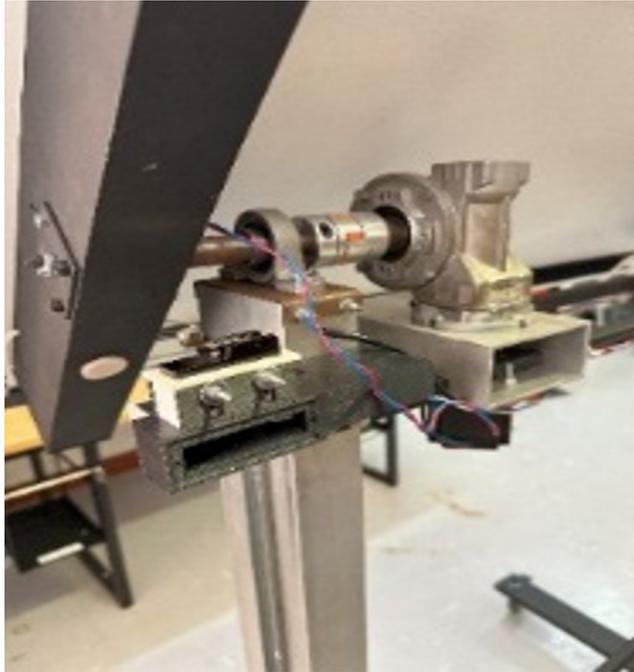


Fig. 10. Worm gearbox and stepper motor assembly.

The rotational motion is fed through the tabletop, causing the left shaft to rotate in the two pillow block bearings. The configuration enables the tabletop to tilt smoothly and securely while maintaining its position when the motor is off. Worm gears are self-locking, which satisfies the locking for this mode. Having the table locked in position without the stepper motor enabled is essential when the desk is not powered on. Lockable castors attached to each side of the horizontal legs allow for mobility and stability when the desk is stationary.

3.3 Electrical design specification

The electrical system has been designed to distribute power effectively to the actuators, motors, and control panel while integrating safety features and user warnings. Figure 10 shows the full wiring schematic, detailing the connections between the power supply, Arduino Mega microcontroller, motor drivers, and peripheral components. In case of an overload or emergency, the E-stop button cuts off all power to the system, preventing further operation. The control panel includes four momentary switches for height adjustments (raise and lower) and tilt adjustments (tilt forward and backward). The choice of momentary switches provided more flexible positioning than preset steps, giving the user complete control over tilt angle and height. A 3D-printed limit switch bracket, shown in figure 11 below, was designed to prevent physical interference between desk components.



Fig. 11. 3D-printed limit switch bracket.

The bracket moves with the leg, ensuring the switches are functional across both sitting and standing modes. The stepper motor is cut out when they are triggered at each end of the tilting range.

3.4 Software and programming aspects

The desk's programming is managed by an Arduino Mega microcontroller, which coordinates the movements of the actuators and motors according to user inputs. The system includes an audible feedback mechanism that activates during any adjustment to height or tilt. The alarm ensures that users know movements, minimizing the risk of accidental adjustments.

4 Performance evaluation, experiments and data analysis

The section outlines the testing procedures conducted to evaluate the functionality and performance of the adjustable work desk in a laboratory where it is desired to be placed. The two crucial aspects of the system, height adjustment, and tabletop tilting, were tested to certify the system's structural integrity, accuracy, and safety.

4.1 Signal testing

The test evaluates the electrical behaviour of the DC motor drivers, particularly aspects such as voltage stability and noise, as the system operates in real-time. The experiment is essential to assess the stability and consistency of the power supplied to the linear actuators. Voltage levels were recorded for both actuators during the raising and lowering operations with minimal load applied.

Signal test results illustrate that both motor drivers output approximately $\pm 9V$ to the linear actuators, indicating that each actuator receives an equal power supply during operations. A higher-quality actuator could reduce the fluctuations in the right actuator voltage readings; however, the current setup adequately meets the project's requirements. Overall, the DC motor output voltage experiment confirms that both actuators perform within acceptable limits. These findings validate the system's capacity to effectively manage the added load on the right side, ensuring reliable operation of the desk's height adjustment functions.

4.2 Performance optimization testing

The test established that adjustable desk's performance and functional characteristics. The results obtained from the performance experiments verify the requirement satisfaction.

4.2.1 Experiment 1: Repeatability on height adjustment

The linear actuators integrated into the telescopic operate using direct current and do not have positional feedback. Fig. 12 illustrates the waveforms of the error in time between the two actuators before and after speed adjustment.

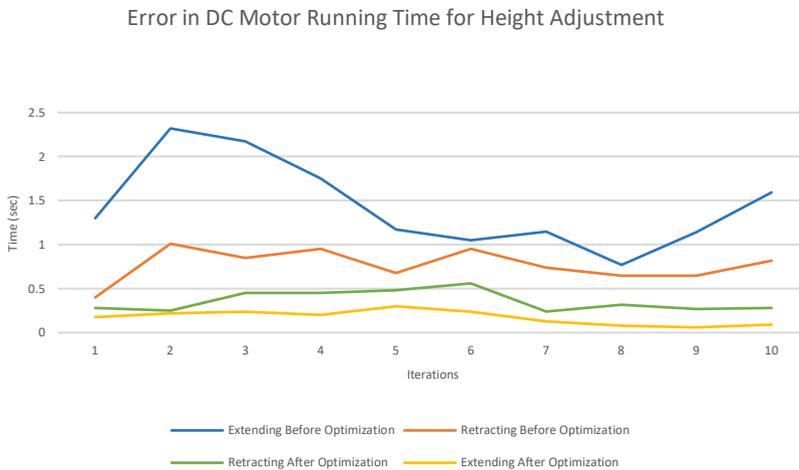


Fig. 12. Raising and lowering time error waveforms.

From figure 12, it is observed that PWM optimization resulted in a decrease in running time of up to two seconds for the extending operation, and up to 0.7 seconds for the retracting operation. These results confirm the effectiveness of PWM optimisation in aligning actuator speeds, which is essential for maintaining accuracy in the desk's height adjustment functionality.

4.2.2 Experiment 2: Tilting repeatability

The experiment aimed to assess the accuracy and repeatability of the rotational mechanism in the adjustable desk's tabletop positioning. Accurate positioning is crucial for the desk's functionality and safety, especially when switching between different user-defined positions. The tabletop was rotated back and forth across its full range, from horizontal to vertical, for 20 repetitions. During each repetition, the angle was recorded at both the horizontal and vertical endpoints to determine any deviation from the ideal 0 and 90 degrees. The graph below visually represents the error for each rotation endpoint over the 20 repetitions.

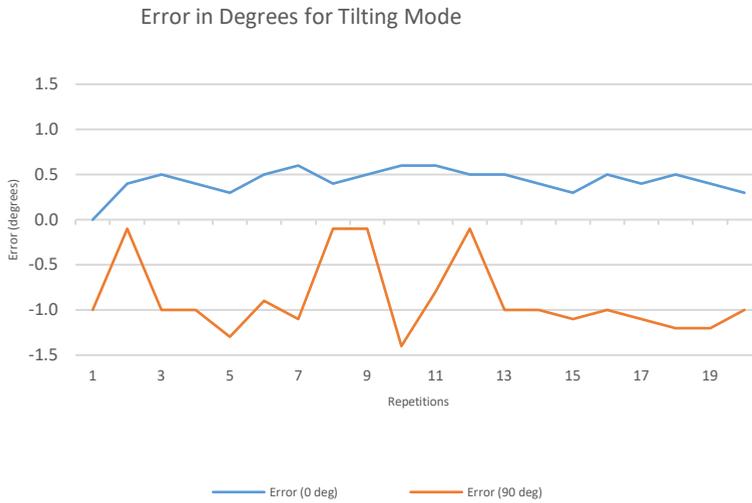


Fig. 13. Error waveforms for tabletop tilting range.

For the zero-degree operation, the error is maintained within the range of 0 and 0.6 degrees. Similarly, for the ninety-degree operation, the error fluctuates between 0 and 1.4 degrees. The findings indicate that the system generally maintains accuracy in reaching both horizontal and vertical endpoints. The readings and statistical results confirm the reliability of the limit switches, demonstrating accurate repeatability across the test cycles.

5 Conclusion

The work presents the design and construction of a multi-functional adjustable desk that meets the outlined requirements for structural stability, ergonomic design, and user-friendly operation. The final design integrates mechanical, electrical, and software components to provide three modes, enhancing user comfort and versatility in a modern workspace. Optimization of the dc motor PWM resulted in a decrease in motor running time during extension and retraction. Additionally, an iterative evaluation of the tilting operation indicates an error range of 0.6 degrees of the zero-degree operation, and an error range of 1.4 degrees for the ninety-degree operation. Several improvements could be considered for future iterations. Utilising higher-quality actuators with built-in positional feedback could enhance accuracy and further reduce the fluctuations observed under load conditions. Additionally, implementing a Bluetooth module to control the desk via a smartphone application could increase its adaptability in various environments. A detailed mechanical, electrical, and programming design of the adjustable work desk, extensive explanation of the construction process and the rigorous testing of the developed prototype has provided a solid foundation for an adjustable desk design that combines practical functionality with structural and ergonomic standards.

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