Research and Practical Design of a Teaching Experiment for an Unbalanced Rod Based on the Principle of Gravity Balance

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Abstract: *This paper introduces a teaching experiment design for an unbalanced rod based on the principle of gravity balance. This unbalanced rod is a purely mechanical mobile rod-balancing mechanism characterized by simplicity in structure, low cost, high efficiency, and reliable safety. The structure is comprised of a ladder frame, rocker, support rod, and a multi-stage adjustable self-locking system. An automatic correction device controls the direction and telescoping length of the support rod by managing the double rocker and shifting the center of gravity to stabilize the unbalanced rod. Experimental data indicates that this design effectively counters external forces on the rod, maintaining stability. This device holds potential for broad applications, such as in stable support structures, industrial tipping alarms, and automatic correction systems.*

Keywords: *unbalanced rod, gravity balance principle, lever principle, automatic correction device.*

1. Introduction

Rods are commonly used objects in human production and daily life, finding applications across various fields, such as industrial automation, transportation, medical equipment, and home use. Their applications primarily focus on enhancing productivity by automating precise actions and pathways in industrial processes, which reduces manual labor, improves efficiency, and increases safety in tasks like automatic braking and steering in transportation to minimize accidents. In the medical field, rods assist in tasks performed by surgical robots or rehabilitation devices, enabling precise and safe operations and improving patient care.[1]

However, in scenarios requiring extensive work areas, the repetitive motion of moving rods up and down is inefficient and inconvenient. Directly standing on the rod to move it risks tipping, leading to potential injury. This design proposes a solution that allows users to operate and move the rod while maintaining balance, thus enhancing usability and efficiency. Currently, most solutions rely on motorized assistance or external force, which incurs high costs and demands significant resources. Past designs both domestically and internationally have explored the stability of rod structures based on principles such as unbalanced dolls, wind resistance devices, precession principles, and resonance in "unbalanced rod" designs.[2]

In conclusion, rods possess vast potential across various domains, yet further improvements in safety are needed. Enhanced technical development, optimized human-machine interaction design, and comprehensive regulations are key to advancing the safety and utility of automated rods, providing greater convenience and security in production and daily life.[3]

2. Principles of Experimental Design

2.1 Description of the Experimental Device

This design applies the unbalanced rod principle to create a balanced system of multiple rods, forming a purely mechanical, mobile unbalanced rod-balancing mechanism that is simple, low-cost, highly efficient, and reliably safe. This design fills a gap in similar rod designs. The unbalanced rod is primarily modeled using SolidWorks, with subsequent analysis and material selection to create a center-of-gravity shift. The structure employs a self-locking system and a hinge structure to achieve both support and movement balance according to dynamic principles. Three main rods create a stable triangular structure comprising a new, safe, unbalanced ladder with a frame, rocker, support rod, and multi-stage adjustable self-locking system. An automatic correction device uses the double rocker to control the support rod's direction and telescoping length while shifting the center of gravity to keep the unbalanced rod mobile. The following provides a detailed explanation of the principle:

The rod's base comprises three long rods forming a triangle, inherently stable, enhancing overall stability. The unbalanced rod principle explains both support balance and movement balance. In support balance, the object's center of gravity is directly above the pivot point, maintaining stillness. In movement balance, as the weight shifts, the center of gravity moves, and when the rod returns to balance, the weight rises, bringing the center of gravity back into alignment. For true "imbalance," mass distribution is uneven, akin to the weighted structure of a roly-poly toy.

The automatic correction device, equipped with an inclinometer, senses the tilt angle, shifting the center of gravity by dropping weights to move a plastic rod. During movement, this ensures the center of gravity remains within the support points, maintaining stability and preventing tipping of the rod.

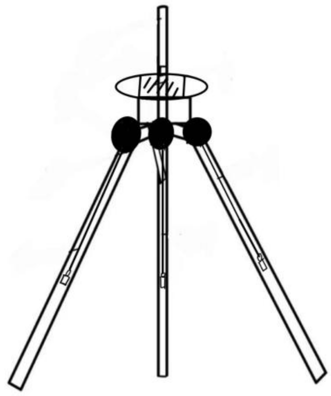

Figure 1 Schematic Diagram of the Device

As long as the center of gravity of a rod remains above its support point, the rod can maintain a balanced state, where the impulse is generated by the oscillation of the automatic correction device: $I = F \cdot t$。If $F \times L_{AB} > G_1 \times 0.5L_{OB} + G_3 \times L_{OB} + G_2 \times 1.5L_{OB}$ (as shown in Figure 2), the lever arm OB gradually decreases during motion, accelerating the counterclockwise rotation of the ladder. Additionally, F (force) is not constant; it acts as an impulse. When point A moves directly above point O, the rod tips over. When F is relatively small, point A cannot reach directly above point O; under the influence of the weights G1, G2 and G3, the rod oscillates around point O and eventually stabilizes.[4]

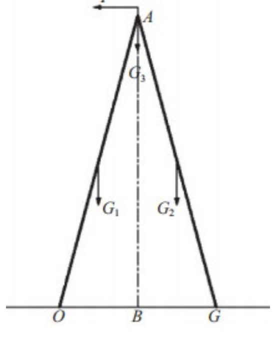

Figure 2 Lever Principle Diagram

2.2 Setup of the Stepper Motor Device

Three stepper motors are used among the three support rods: these motors are interconnected with a microcontroller and an inclination sensor to detect tilt and adjust the weights, allowing for controlled shifts in the center of gravity. When the inclination sensor detects a tilt in the rod, it activates the descent of the weights to shift the center of gravity accordingly. The stepper motors then enable rod movement to maintain stability.

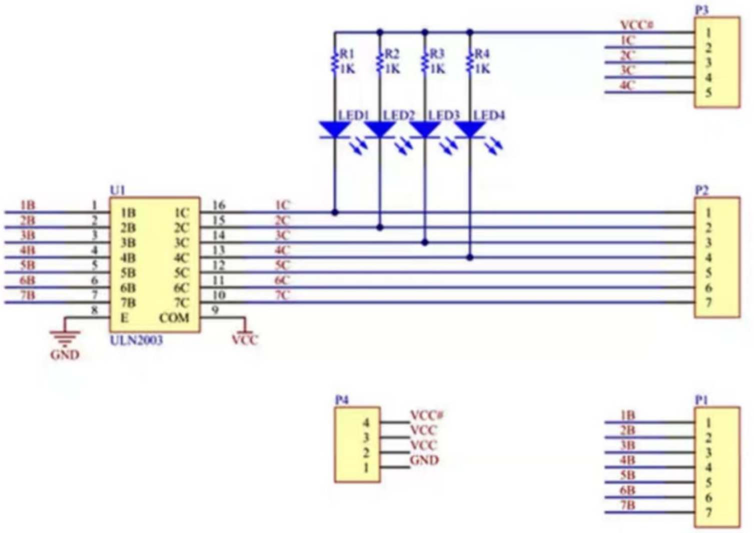

Figure 3 Stepper Motor Principle Diagram

2.3 Setup of the Inclination Sensor Device

The inclination sensor in this device is connected to a microcontroller and stepper motors, detecting the tilt angle of the rod. Upon detecting a tilt, the device responds with automatic correction. The microcontroller-controlled correction system commands the stepper motors to rapidly adjust the rod's position to maintain balance.[5]

When the inclination sensor measures a horizontal tilt angle that exceeds the preset θ angle (tilting in any direction, causing the Z-axis to deviate from the vertical), the microcontroller commands the stepper motors to adjust the position of the weight, thereby shifting the center of gravity of the entire apparatus and maintaining rod stability. If the tilt is below the θ angle (i.e., near horizontal), the microcontroller keeps the stepper motors inactive. The default θ angle is set to 16 degrees but can be adjusted within a range of 1 to 45 degrees through a configurator or TTL serial port.

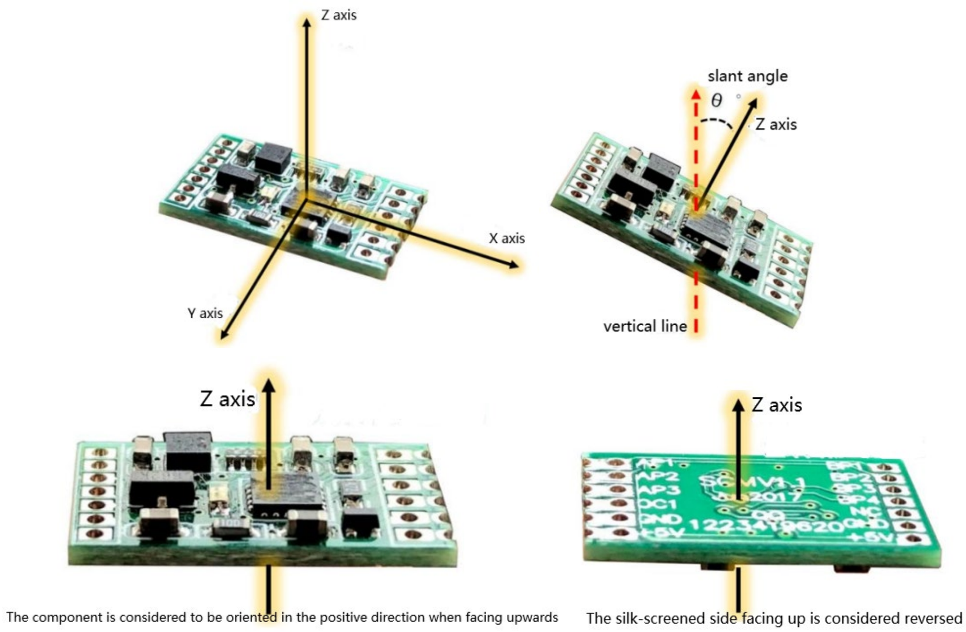

Figure 4 Inclination Sensor

3. Experimental Setup

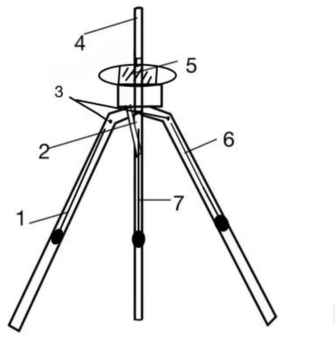

Figure 5: Simplified Diagram of the Apparatus

Support Rod a: Adjusts the center of gravity by moving the attached weight via the stepper motor.

Weight: Shifts the object's center of gravity by moving up or down.

Stepper Motor: When the rod tilts, the stepper motor activates to carry out automatic correction of the apparatus.

Main Rod: The primary rod of the setup.

Inclination Sensor: Detects the tilt angle of the rod.

Support Rod b: Adjusts the center of gravity by moving the attached weight via the stepper motor.

Support Rod c: Adjusts the center of gravity by moving the attached weight via the stepper motor.

When the rod tilts, the center of gravity shifts. The inclination sensor detects this tilt and triggers a response, controlling the stepper motor to rotate and cause the weight on the opposite support rod to descend, shifting the center of gravity back. As the center of gravity approaches the center, the stepper motor rotates in the reverse direction, raising the weight and stabilizing the center of gravity, thus ensuring the stability of the rod.

Figure 6: Schematic Diagram of Device Movement

4. Experimental Data

A series of fixed forces were applied to simulate external forces acting on the rod, causing it to tilt. A stopwatch was used to measure the time in place of directly measuring the tilt speed of the rod. Under several constant forces, the inclination sensor and optical angle gauge were used to measure the tilt angle and the descent distance of the weight when the rod returned to a stable state at its fastest rate.[6]

Using Solidworks for 3D modeling, minor chamfers and fillets in non-critical areas were reduced, threading holes in certain parts were minimized, and structural adjustments were made to challenging parts. The above data were then modeled in 3D to determine the optimal correction angle and time when the inclination sensor and stepper motor-based auto-correction device operated in tandem. Based on this data and considering weight requirements, materials were selected to achieve optimal stability for the entire structure.

Inclination Angle: 15 degrees

The time required to tilt down to the angle（s）	0.375	0.350	0.325	0.300	0.275	0.250
Descending distance /（cm）	13.2	14.8	16.9	20.5	24.9	31.6

Inclination Angle: 20 degrees

The time required to tilt down to the angle（s）	0.375	0.350	0.325	0.300	0.275	0.250
Descending distance /（cm）	26.5	30.1	31.5	32.6	33.9	34.2

Inclination Angle: 25 degrees

The time required to tilt down to the angle（s）	0.375	0.350	0.325	0.300	0.275	0.250
Descending distance /（cm）	29.1	31.1	32.6	33.2	34.8	36.1

Inclination Angle: 30 degrees

The time required to tilt down to the angle（s）	0.375	0.350	0.325	0.300	0.275	0.250
Descending distance /（cm）	29.7	31.6	33.2	33.9	35.1	36.8

Conclusion

Through motion analysis and practical operation, this design of a self-righting rod based on the principles of gravity balance and leverage effectively combines tilt sensors with stepper motors. By controlling the descent of a counterweight to shift the center of gravity, it ingeniously merges gravity sensing with leverage principles, creating a self-righting rod based on leverage theory. The design considered the impact of different external forces on the rod and its tilt angle, using a “median value” method to ensure the instrument's accuracy. The triangular support frame itself provides inherent stability, and in combination with stepper motor control, ensures the precision of the experimental apparatus. This device has broad applications across various fields: from everyday stabilizing supports to industrial tilt alarm and correction systems. With its sensing and response capabilities, it boasts high timeliness, stability, precision, and showcases both innovation and practicality.

Fund Project

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