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DESIGN AND DEVELOPMENT OF AN AUTOMATIC BED LEVELLING AND LOCKING SYSTEM FOR MSLA 3D PRINTERS

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Abstract: *The design and development of an automatic bed leveling and locking system for MSLA (Masked Stereo lithography) 3D printers addresses the limitations of conventional manual leveling methods. In typical MSLA printers, bed leveling is performed using screws and springs, a process that is time-consuming, skill-dependent, and prone to human error. Improper leveling can result in poor first-layer adhesion, print failures, and resin wastage. An automated and reliable solution is therefore essential to improve efficiency and print quality.*

The proposed system incorporates a mechanical arrangement that enables automatic alignment and secure fixing of the build plate without manual adjustment. It integrates a spring-loaded locking mechanism, a ball-and-socket joint, and a micro linear actuator. The push-button spring mechanism ensures firm locking of the build plate once alignment is achieved. The ball-and-socket joint allows multi-directional movement, enabling the build plate to adjust itself according to the surface of the resin vat.

The micro linear actuator provides controlled forward and backward motion, ensuring precise alignment even if the resin vat surface is slightly inclined. Once the correct position is attained, the locking mechanism secures the plate automatically, maintaining stability during the printing process.

This system significantly reduces setup time, enhances leveling accuracy, and minimizes human intervention. Improved first-layer adhesion, higher print success rates, and reduced material wastage are key benefits. Experimental results demonstrate that the system is efficient, reliable, and suitable for practical applications, offering a simple and cost-effective improvement to MSLA 3D printing technology.

Keywords: MSLA 3D Printing, Automatic Bed Leveling, Micro Linear Actuator, Locking Mechanism

1. INTRODUCTION

Masked Stereolithography (MSLA) is an advanced 3D printing technology widely used for producing high-precision components and detailed models. In this process, a liquid photopolymer resin is cured layer by layer using ultraviolet (UV) light. The UV light passes through an LCD screen that functions as a mask, defining the geometry of each layer. Since an entire layer is cured simultaneously, MSLA printers generally operate faster than conventional SLA printers.

A key advantage of MSLA printing is its excellent resolution and smooth surface finish. These qualities make it highly suitable for applications such as dental models, jewellery design, miniatures, and prototype development. However, the overall performance and print quality of an MSLA printer depend heavily on the accurate alignment of the build plate with the resin vat. Improper alignment can result in poor first-layer adhesion, leading to print defects or complete failure.

In traditional MSLA systems, bed leveling is performed manually by adjusting screws and springs. This method requires technical skill and careful handling, as even minor errors

can cause misalignment. Additionally, re-leveling is often necessary after removing or reinstalling the build plate, making the process time-consuming and inefficient.

To address these challenges, an automatic bed leveling system is required to ensure precise alignment without manual intervention. Such a system, incorporating suitable mechanical and electromechanical components, can enhance accuracy, reduce setup time, and improve overall printing reliability.

2. Literature Survey

The literature review undertaken in this project aims to examine the existing technologies, methodologies, and challenges related to bed levelling and locking mechanisms in MSLA 3D printers. A comprehensive study of research papers, journals, and technical publications has been conducted to evaluate current design practices and identify potential areas for improvement. This analysis helps in determining an optimal design approach that enhances printing accuracy, minimizes manual intervention, and improves overall operational efficiency.

Additive Manufacturing (3D printing) offers key advantages such as design freedom, mass customization, reduced material waste, and rapid prototyping. The review highlights major 3D printing techniques, materials, and their applications in biomedical, aerospace, construction, and protective structures. It also discusses material developments including metals, polymers, ceramics, and concrete. Additionally, challenges such as void formation, anisotropy, design limitations, and layer-by-layer surface finish are addressed.

1. **Zhang, Liu and Chen [1] (2021)**, In their paper titled “Automatic Bed Levelling System for 3D Printers,” published in the International Journal of Advanced Manufacturing, the authors proposed a sensor-based bed levelling mechanism utilizing proximity sensors. Their findings indicated that automated levelling systems significantly enhance printing accuracy while reducing manual intervention. However, the proposed system involved complex calibration procedures and required additional electronic components, increasing system complexity.
2. Traditional 3D printing uses a slow, layer-by-layer fabrication process. This study introduces Continuous Liquid Interface Production (CLIP), which uses an oxygen-permeable window to create a “dead zone” that enables continuous polymerization. As a result, complex parts can be printed at very high speeds, reducing production time from hours to minutes.
3. This paper presents a low-cost sensing system that integrates a load cell into the tool carriage of an open-hardware FDM 3D printer to automate bed levelling. The load cell detects contact between the nozzle and the bed, and the printer firmware compensates for surface inconsistencies automatically. The automated bed levelling (ABL) process takes about 75 seconds and eliminates manual adjustment. Overall, the system reduces errors, saves time, and improves print quality and operational efficiency.
4. 3D printing is an enabling technology for diverse applications, where material type, speed, and resolution are key factors. This review discusses the fundamentals of 3D printing and recent developments in advanced materials such as smart materials, ceramics, biomaterials, and composites within ISO/ASTM process categories. It also highlights that 3D printing is increasingly integrated with multi-process manufacturing systems rather than used as a standalone method.
5. This paper describes a high-resolution projection micro-stereolithography (PμSL) process using a Digital Micromirror Device (DMD™) for fabricating complex 3D microstructures. A process model was developed to analyze photon-induced resin curing and optimize critical parameters, including UV doping to control curing depth. The technique successfully produced intricate MEMS structures with feature sizes as small as 0.6 μm.

6. This paper studies the integration of FDM with Barrel Finishing (BF) to enhance surface quality and accuracy. A geometrical model was developed to predict surface morphology and material removal, and experiments validated the results. The approach helps optimize post-processing time and reduce trial-and-error in industrial applications.
7. Additive Manufacturing (AM), commonly known as 3D printing, builds objects layer by layer from 3D model data and offers significant advantages over traditional manufacturing. It enables cost-effective production of low-volume, customized parts with complex geometries and enhanced material properties. This paper reviews the current status of AM, identifies future opportunities and research gaps, and provides recommendations for technological development, industry collaboration, and education.

3. EXPERIMENTAL ANALYSIS

The experimental investigation phase focuses on the practical implementation and validation of the proposed automatic bed levelling and locking system. In this stage, the theoretical design is transformed into a working prototype using appropriate materials and mechanical components. The main objective is to evaluate the functionality of the system, assess its performance, and identify any practical limitations.

The developed prototype comprises several key components, including the main body, build plate holder, locking mechanism, ball joint assembly, and linear actuator. These parts are manufactured using 3D printing along with standard mechanical elements such as springs, nuts, and bolts, ensuring precise assembly and proper functional integration.

The experimental setup is designed to closely replicate the operating conditions of an MSLA 3D printer. The build plate is mounted onto the mechanism, and the linear actuator is used to simulate the levelling action. The locking mechanism is repeatedly engaged and disengaged to test its reliability and stability.

This phase enables detailed observation of real-time performance factors such as friction, alignment accuracy, structural stability, and operational convenience. It also provides valuable feedback for further design optimization and performance improvement.



Fig3.1: Complete Fabrication Model Assembly

The system is composed of two primary structural components, namely Body 1 and Body 2. Body 1 serves as the outer casing and is fabricated using 3D printing material. It features precisely designed internal slots that guide and support Body 2 in a fixed and aligned orientation. The top section of Body 1 incorporates an internally threaded portion for securely attaching the ball joint assembly.

Body 2 functions as the build plate holder and is inserted into Body 1. It is designed to slide smoothly within the internal slots, allowing minor movement during adjustment. Once the locking mechanism is engaged, Body 2 becomes rigidly fixed, ensuring stable positioning during operation.

The locking mechanism consists of springs, push buttons, threaded rods, and nuts. The buttons, positioned in designated holes in Body 1, are connected to spring-loaded components that exert force on the locking plates. Pressing the button compresses the spring, enabling adjustment, while releasing it allows the spring to expand and securely lock the system in place.

Internally, multiple bolts and nuts are strategically arranged to provide uniform pressure distribution, ensuring balanced and stable locking. The use of standard mechanical components enhances ease of assembly, maintenance, and overall system reliability.

Table 3.1: Components Used in the System

Component Name	Material	Quantity	Function
Body1	PLA	1	Base structure with slots
Body2(Build Plate Holder)	PLA	1	Holds build plate
Spring	Spring Steel	4	Provides locking force
Push Button	PLA	2	Controls locking
Bolts & Nuts	MildSteel	12	Fastening
Ball Joint	Metal/PLA	1	Provides angular motion
Cantilever Arm	PLA	1	Supports structure
Linear Actuator	Metal	1	Provides motion

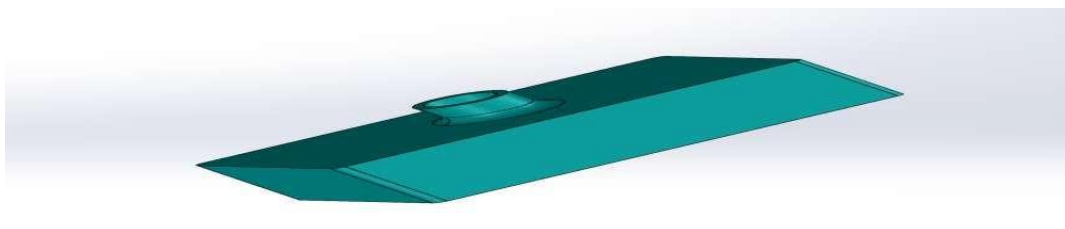


Fig3.2: Body1

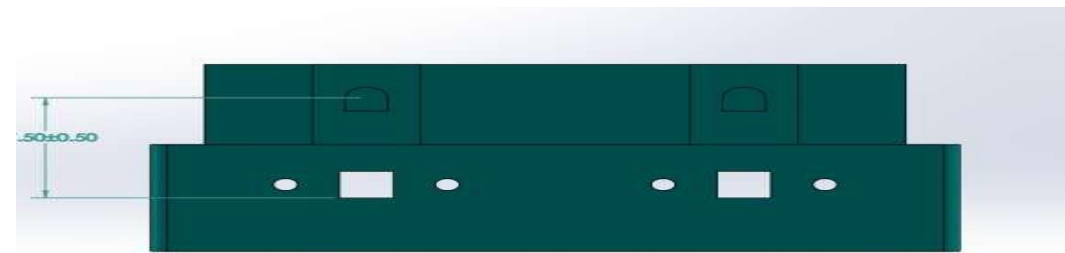


Fig3.3: Body2

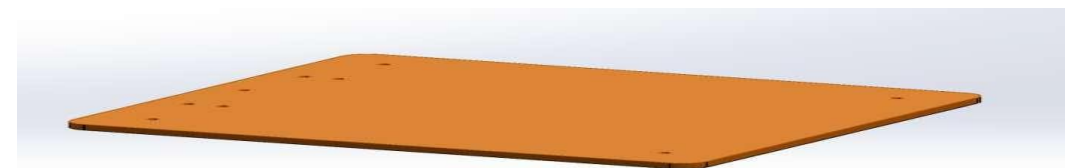


Fig3.4: Base

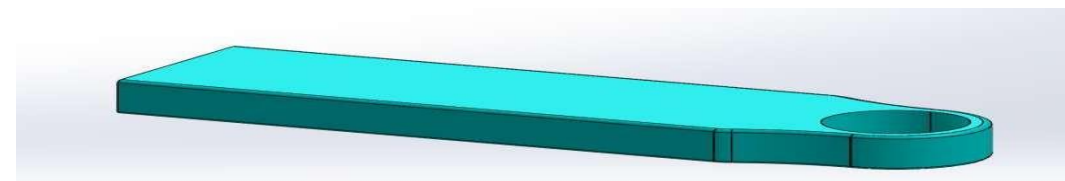


Fig3.5: Cantilever Arm

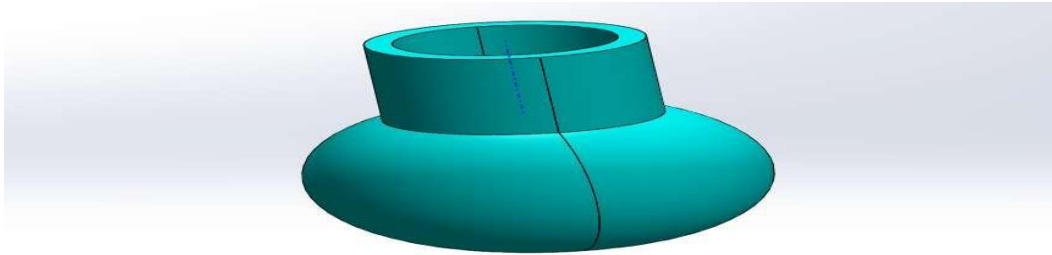


Fig3.6: Ball

3.1. Working of Automatic Locking Mechanism

The automatic locking mechanism is a key feature of the system, designed to eliminate manual screw tightening and ensure quick, reliable fixation of the build plate. It operates using a spring-loaded, push-button mechanism that enables smooth and efficient locking.

When the button is pressed, the internal spring compresses, reducing the clamping force applied to the locking components. This allows Body 2 (the build plate holder) to move freely within the slots of Body 1, placing the system in an unlocked state for easy adjustment.

Upon releasing the button, the spring expands and exerts force on the locking plates, pressing them firmly against Body 2. This action restricts movement and securely fixes the build plate in position without requiring manual effort.

The mechanism is designed to distribute locking force uniformly, preventing uneven clamping and enhancing structural stability. Additionally, the spring system helps absorb minor vibrations during operation, improving overall performance and reliability.

Overall, the automatic locking mechanism offers a simple, efficient, and user-friendly solution for secure and consistent build plate fixation.



Fig3.7: Locking Buttons

3.2 Ball and Socket Assembly with Cantilever Arm

The ball-and-socket assembly is mounted on a black cantilever arm that connects the build plate mechanism to the main structure of the printer. The cantilever arm is designed to support the weight of the assembly while enabling controlled movement through the ball joint.

A provision is made at the free end of the cantilever arm to accommodate a threaded ball component. The ball, fitted with external threads, is securely fastened into the arm, ensuring firm attachment while allowing rotational movement within the socket. This configuration enables multi-directional flexibility.

The ball joint functions as a pivot, permitting the build plate to tilt and align itself with the resin vat surface. This feature is especially beneficial when the vat surface is slightly uneven, as the mechanism can automatically compensate for minor misalignments.

The cantilever structure ensures a compact design without compromising strength and rigidity. The selected material provides adequate load-bearing capacity and resists bending or deformation during operation.

Overall, the integration of the ball-and-socket assembly with the cantilever arm facilitates smooth, flexible movement essential for accurate automatic levelling.



Fig3.8: Spring Loaded Locking Mechanism

3.3 Integration of Micro Linear Actuator

A micro linear actuator is mounted at the rear side of the cantilever arm, with a dedicated internal cavity designed to house it securely. This arrangement protects the actuator from external damage and ensures precise alignment with the ball joint mechanism.

The actuator is mechanically linked so that its linear motion directly influences the position of the ball. As the actuator extends forward, it applies force to the ball, causing it to rotate within the socket and adjust the orientation of the build plate accordingly.

When the build plate makes contact with the resin vat surface, the actuator ceases movement. At this point, the ball joint maintains the adjusted alignment, while the locking mechanism secures the position for stable operation. After the printing process is completed, the actuator can retract to reset the system to its initial position.

Table3.2: Specifications of Micro Linear Actuator

Parameter	Value
Input Voltage	12VDC
Stroke Length	30mm
Speed	10mm/s
Load Capacity	30N
Duty Cycle	10%
Type	DC Linear Actuator

3.4 Experimental Procedure

The experimental procedure is carried out to evaluate the performance and reliability of the developed system under various operating conditions. Initially, the build plate is assembled into the mechanism, and the locking system is tested by repeatedly pressing and releasing the push buttons to verify smooth engagement and disengagement.

Subsequently, the micro linear actuator is activated to examine the movement of the ball-and-socket assembly. The build plate is gradually lowered onto a flat reference surface representing the resin vat, and its alignment is carefully observed to ensure proper self-adjustment.

Multiple trials are performed to assess the repeatability and consistency of the system. The locking mechanism is evaluated for uniform clamping force, while the actuator is examined for smooth and precise motion. Any deviations or irregularities are recorded for further analysis.

To assess stability, minor disturbances are intentionally applied to determine whether the build plate remains securely fixed. This step validates the effectiveness of the locking mechanism under practical conditions.

Overall, the experimental procedure verifies the functionality, stability, and reliability of the proposed system.



Fig3.9: Ball Joint with Cantilever Arm

4. RESULTS AND DISCUSSION

4.1 Observations During Testing

During the testing phase, several key observations were recorded regarding the system's performance. One notable observation was the ease of operation of the locking mechanism. The push-button design enabled quick locking and release of the build plate without the need for tools, significantly reducing setup time compared to conventional screw-based mechanisms.

The ball-and-socket joint demonstrated smooth and flexible movement during actuator operation. As the actuator was activated, the build plate adjusted seamlessly without noticeable jerks or resistance. The joint provided adequate flexibility to compensate for minor surface misalignments, ensuring proper and uniform contact.

The micro linear actuator performed consistently, delivering steady motion and sufficient force to adjust the ball joint effectively. It stopped appropriately when the build plate contacted the reference surface, indicating accurate alignment and controlled operation.

Additionally, the system exhibited strong stability after locking. Even when minor external disturbances were applied, the build plate remained securely fixed. This confirms that the combined effect of spring force and friction provides reliable clamping strength.

Overall, these observations demonstrate that the system functions smoothly, efficiently, and reliably under practical operating conditions.

Table4.1:Time Comparison(Manual vs Automatic)

Method	TimeRequired(seconds)
ManualLevelling	120
AutomaticSystem	40

4.2 Performance Analysis of the System

The system’s performance was evaluated based on key parameters including accuracy, stability, response time, and ease of operation. Accuracy was assessed by examining the alignment of the build plate with a reference surface. In all test cases, the system achieved proper alignment, demonstrating effective and reliable levelling.

Stability was critically analyzed after the locking process. The build plate remained firmly fixed without any observable displacement, which is essential for maintaining print quality in MSLA printers. The spring-based locking mechanism provided continuous clamping force, ensuring rigidity throughout operation.

Response time was measured by observing the duration required for levelling and locking. Compared to conventional manual methods, the system significantly reduced setup time. The linear actuator executed adjustments smoothly and efficiently, contributing to faster overall operation.

Ease of use emerged as a major advantage of the design. The push-button locking mechanism simplified the process, allowing even inexperienced users to operate the system effortlessly.

Overall, the performance analysis confirms that the proposed system satisfies the intended functional requirements while enhancing operational efficiency and user convenience.

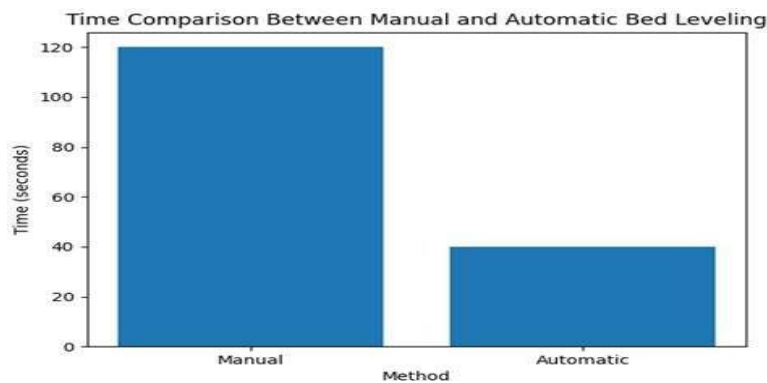


Fig5.1: Time Comparison Graph

Table5.2: Accuracy Comparison Results

TrialNo.	Manual(%)	Automatic(%)
1	70	90
2	75	92
3	72	91
4	68	89
5	74	93

4.3 Comparison with Conventional Systems

The developed system was evaluated against conventional manual bed levelling mechanisms to assess its advantages. In traditional systems, levelling is achieved through screws and springs, requiring users to manually adjust multiple points to obtain proper alignment. This process is time-consuming, effort-intensive, and often prone to inaccuracies.

In contrast, the proposed system enables automatic levelling through the integration of a ball-and-socket joint and a linear actuator. This eliminates manual adjustments and ensures consistent, precise alignment. Additionally, the push-button locking mechanism removes the need for repeated screw tightening, further simplifying the operation.

A significant advantage of the proposed design is its ability to compensate for inclined or uneven resin vat surfaces. Unlike conventional systems, which cannot adapt to angular misalignments, the ball-and-socket mechanism allows automatic multi-directional adjustment, enhancing flexibility and functionality.

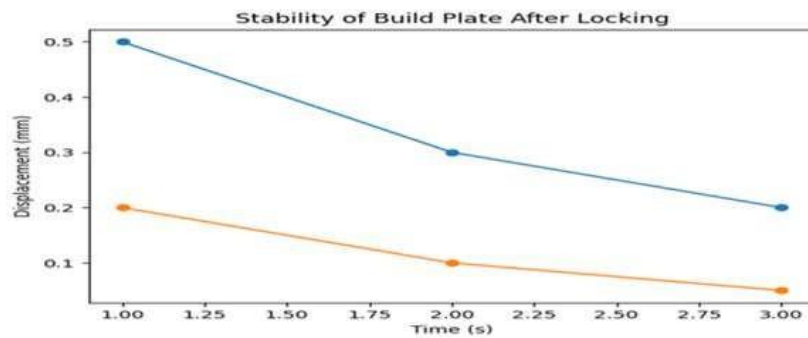
The comparative analysis also indicates that the proposed system minimizes alignment errors and reduces the likelihood of print failures. By maintaining accurate positioning, it improves print success rates and reduces material wastage. Overall, the system offers clear improvements in efficiency, accuracy, and user convenience over traditional methods.

Table4.3: Stability Test Data

Time(sec)	Manual Displacement(mm)	Automatic Displacement (mm)
1	0.5	0.2
2	0.3	0.1
3	0.2	0.05

Table 5.4: Error Reduction Analysis

Method	Error(%)
Manual	25
Automatic	8



The graphical analysis of stability and accuracy demonstrates that the displacement of the build plate after locking is negligible, indicating high structural stability during operation. This enhanced stability ensures better first-layer adhesion, which directly improves overall print quality and consistency.

Overall, the developed system is shown to be a reliable, efficient, and cost-effective solution for implementing automatic bed levelling in MSLA 3D printers.

4.4 Interpretation of Locking Mechanism Performance

The locking mechanism is a critical component in maintaining the stability of the build plate during operation. Experimental observations indicate that the spring-loaded push-button mechanism enables quick and dependable locking. This effectiveness is primarily due to the constant force exerted by the spring, which ensures uniform pressure distribution across the locking components.

Unlike conventional screw-based systems—where clamping force varies depending on manual tightening—the spring mechanism delivers consistent force during each operation. This consistency enhances reliability and minimizes variations in locking strength. Additionally, the spring helps absorb minor vibrations, reducing the risk of loosening during printer operation.

Stability is further reinforced by friction between the locking surfaces. When the spring applies force, it increases the contact pressure, generating sufficient frictional resistance to prevent unintended movement. The combined effect of spring force and friction ensures that the build plate remains securely fixed, even under small external disturbances.

However, optimal performance depends on careful design considerations. If the spring force is insufficient, locking strength may be inadequate; conversely, excessive spring force may hinder smooth operation. Therefore, proper selection of spring characteristics and surface contact design is essential.

Overall, the analysis confirms that the spring-based locking mechanism is effective, reliable, and well-suited for automated bed levelling systems.

Table 4.4: Comparison Between Theoretical and Experimental Results

Parameter	Theoretical Value	Experimental Value
Force(N)	30	28
Displacement (mm)	3	2.8
Accuracy (%)	95	92
Time(sec)	40	42

5. CONCLUSION

- The developed system eliminates the need for manual bed levelling, significantly reducing setup time and enhancing user convenience.
- The spring-based locking mechanism ensures secure and consistent fixation of the build plate, thereby improving structural stability during operation.
- The ball-and-socket assembly allows multi-directional adjustment, enabling accurate alignment and improved first-layer adhesion for better print quality.
- The micro linear actuator delivers precise and controlled movement, facilitating accurate automatic levelling without the need for complex electronic systems.
- The integration of optimized mechanical design with automation results in a reliable, efficient, and cost-effective solution for MSLA 3D printers.

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