Development of Ophthalmology Eye Examination Device Using 3D Printing Technology

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Abstract: *Ophthalmoscopy is a method of teaching ophthalmology that often relies on theoretical lectures and lacks hands-on experiences, resulting in limited practical exposure for students. This gap in practical training hinders students' understanding and proficiency in performing eye examinations, necessitating an innovative educational device to address this issue. This project aims to design and fabricate a 3D printed ophthalmology eye examination device for ophthalmology students with interactive features, lightweight, ergonomics, affordable in price and gives accurate results through the visualization of fundus image. The process involved utilizes 3D scanning technology, CAD software, and 3D printing techniques. In conclusion, the development of a mechanized 3D-printed ophthalmology eye examination device represents a substantial advancement in student learning in the field of ophthalmology. The addition of mechanisms in the device provides a more realistic and interactive learning experience, fostering practical skill development and deeper theoretical understanding.*

Keywords: Ophthalmoscopy; Eye Examination Device; 3D Modelling; Switchable Fundus Image; Iris Movement Mechanism.

1. INTRODUCTION

1.1 Ophthalmology

The field of ophthalmology is experiencing a transformative shift in how eye diseases are detected, diagnosed, and treated, driven by the emergence of computer-based deep learning (DL) technology. DL, a rapidly growing branch of machine learning, involves analysing vast databases and comparing results against established knowledge, paving the way for innovative practices in ophthalmology [1].

Ophthalmologists heavily rely on pattern recognition through direct or indirect visualization of the eye and its surrounding structures to diagnose diseases. Advancements in diagnostic technology have enabled the presentation of these structures in digital form, enhancing the information available to doctors. Given its reliance on visual information, ophthalmology is an ideal field to leverage DL algorithms. Ophthalmoscopy, a crucial practice for eye examination, allows medical practitioners to inspect fundus images, including arteries, veins, and the central nervous system, in living, intact patients [2]. Early diagnosis and proper treatment based on ophthalmoscopy findings play a crucial role in detecting disease severity and preventing disease progression.

Various ophthalmoscopy techniques have been developed for ophthalmology students' training and examination. However, the available options range from overly complex and expensive devices to simplistic, non-interactive ones that do not adequately cater to students' learning needs [3]. As a result, students may not gain the practical experience required to sharpen their skills in performing eye examinations.

1.2 Ophthalmoscopy

Ophthalmoscopy is used by healthcare professionals to examine the retina and diagnose eye diseases. The eye is a complex system that bends light to produce high-quality images processed in the visual cortex. The cornea and lens are the refractive components, with the cornea providing most of the focusing power. Ophthalmoscopy helps detect and evaluate eye conditions, aiding in the diagnosis of diseases [4]. According to Wang, dilated primary care fundus exam sensitivity is 79% and specificity is 82% [5]. The test is part of a routine eye exam to detect issues. For example, Optometrists can screen for eye diseases that affect blood vessels using ophthalmoscopy and may recommend it if the patient has hypertension or diabetes [6]. Ophthalmoscopy is also taught to medical students in preparation for their clinical years, during which they are expected to demonstrate competency [7]. Direct ophthalmoscopy allows doctors to see patients' retinas and ocular media. Practitioners will utilize a hand-held ophthalmoscope to magnify and illuminate the patient's eyes. Direct ophthalmoscopy shows retina in detail visualization. This strategy may calm patients and make fundus viewing easier for practitioners [8]. In 2004, Chung and Watzke proposed a simple device for direct ophthalmoscopy: a short, wide plastic canister with a 37mm retina image at the base and an 8mm hole on the lid that acts as a dilated pupil. This approach is hampered by high-light reflection, low-quality retina images, and limited image access [9]. Figure 1 shows a device developed by Kyoto called The EYE Exam Simulator and The Eye Retinopathy Trainer that was developed by Adam. By adjusting the pupil, users of both types can see more retinal images. Handheld ophthalmoscopes will be used during this examination, providing students studying to be ophthalmologists with additional guidance from experienced people [10].

1.3 Human Eye

The human eye is a complex optical system with various dimensions that contribute to its overall function [11]. Understanding these dimensions is crucial in fields such as ophthalmology, optometry, and vision research [12]. The dimensions of the human eye vary among individuals but generally fall within a specific range. The axial length of the eye is an important measurement used in various diagnostic procedures, such as for calculating intraocular lens power in cataract surgery. The axial length refers to the distance from the cornea to the retina along the eye's central axis. In adults, the average axial length ranges from approximately 22 mm to 24 mm. The lens, a flexible structure located behind the iris, is responsible for focusing incoming light onto the retina. The lens diameter ranges from approximately 9 mm to 10 mm [13]. The dimensions of the human eye are not static and can change throughout life. Factors such as age, refractive error, and certain medical conditions can influence these measurements. Understanding the dimensions of the human eye aids in the design and development of various eye-related technologies, such as contact lenses, intraocular lenses, and ophthalmic surgical instruments.

1.4 3D Printing Technology

3D printing is a new technique that allows CAD model drawings to be printed into three-dimensional objects. Plastics, resin, metals, and other materials can be utilized in 3D printing depending on the desired application. 3D printing has become essential in medicine and health care. 3D printing is an emerging technology that has not yet been defined and may provide enhanced educational opportunities for trainees, especially for low-volume, low-visibility, high-risk operations [14]. With the use of 3-D printing, planned surgery that required the creation of patient-specific anatomy can be successful [15]. Furthermore, material properties affect the recognition of predetermined geometries. All these factors affect the 3D scaffold's mechanical properties and performance [16]. Fused Decomposition Melting (FDM) is a suitable 3D Printing to use as a medical appliance. As stated by Xingjian Wei, FDM has some eminent advantages. As a first advantage, FDM printers and materials are cheaper than most 3D printers (less than $100/kg). Second, unlike other printing processes, FDM can produce extremely large objects [17].

The application of finite element methods in the realms of biomechanics and bioengineering holds widespread significance for assessing stresses and strains within complex mechanical systems [18]. The terms finite element analysis (FEA) and finite element modelling (FEM) are often used interchangeably to refer to computer-based stress analysis techniques employed when intricate shapes, diverse materials, or complex loading histories resist analytical approaches [19]. FEA provides a streamlined avenue for development and assessment, eliminating the necessity for extensive physical prototypes and significantly reducing time expenditure. The finite element analysis was used to predict the 3D model's level of strength [20].

The limitations of the existing device options are costly, as well as the fundus image. As a result, more affordable alternatives are less interactive and lack essential functions, hindering students' learning experiences using 3D printing technology. To address these challenges, this study is to develop an affordable and technologically advanced eye examination device that offers ergonomic design, ease of manufacturing, user-friendliness, and interactive features.

2. METHODOLOGY

The project focuses on developing an eye examination device for ophthalmologist students, which includes a mannequin head and realistic fundus images. It aims to create eye models with functional mechanisms using 3D scanning, modelling, and printing processes. Software such as Autodesk Fusion 360 and Ultimaker Cura will be utilized for design, analysis, and simulation. Different fundus images will be used as samples, and a desktop FDM 3D printer will be employed. The project will be conducted at Biomec Lab, UiTM, following the engineering design process.

2.1 Development of 3D Model

3D scanning is a non-contact, non-destructive technology that uses laser light to capture a real object's exact size and shape. This study uses a 3D scan to capture a head mannequin as shown in Figure 1. 3D scanning accurately captures the curved surfaces and complex geometry of the face. In the Figure 2 shows the result of CAD model after scanning and convert to STL files.

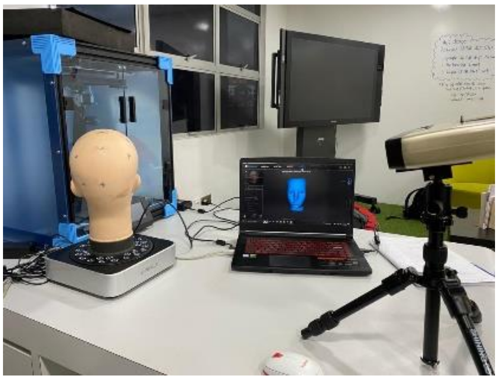

Fig. 1. 3D scanning process.

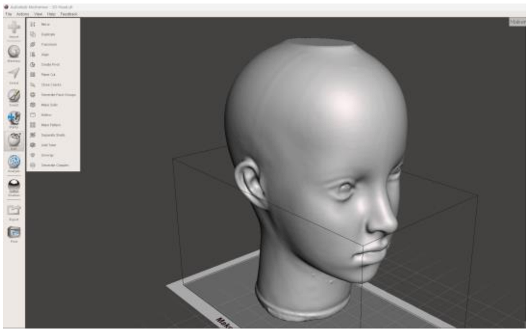

Fig. 2. CAD model in STL files.

2.2 Finite Element Analysis

Finite Element Analysis was conducted on the fundus image frame of the eye examination device to assess critical factors, including von Mises stress and displacement. The simulations were performed with assumption loads of 10N, 50N, and 100N applied to specific regions of interest. The objective was to comprehensively evaluate the frame's structural integrity and performance under varying stress levels. In the simulation, forces were applied at the center of the object, while the ends of each side were constrained as fixed supports as shown in Figure 3.

For finite element analysis, the data for the material are first set up according to Table 1. Two materials, PLA and ABS, were tested in the analysis to understand their respective responses to the applied loads. PLA is known for its favorable properties like low density and ease of 3D printing, and compared with ABS, which exhibits higher strength and durability. Table 1 shows the material properties of PLA and ABS materials.

Table 1. Mechanical properties of ABS and PLA material

Material	Density (kg/m3)	Young's Modulus (MPA)	Poisson Ratio (MPa)
PLA	$1.3\text{x}10^{-6}$	3500	0.38
ABS	$1.06\text{x}10^{-6}$	2240	0.38

Fig. 3. Load applied on the fundus image frame load.

2.3 Fabrication of 3D Model

To prepare the components for 3D printing, each file of the designed parts underwent rendering in Ultimaker Cura. This step involved setting the infill percentage between 10% and 30%, adding supports or adhesion for better printing, previewing the printing process, and determining the weight of each component. Calibration of the 3D printer, whether manual or automatic, was performed to ensure accurate and high-quality prints. The 3D printer builds the device layer by layer, following the instructions from the sliced model. During the printing process, constant monitoring is conducted to identify any potential issues, such as nozzle clogs or material inconsistencies. Quality control checks are performed to ensure that each layer adheres correctly and that the print progresses smoothly. Figure 4 shows an example of a prototype mouth part model during the 3D printing stage.

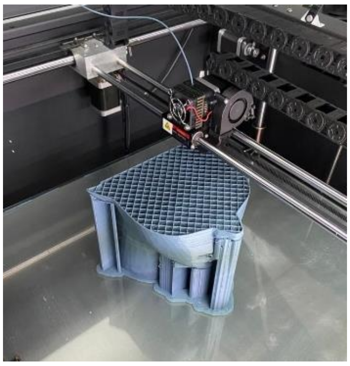

Fig. 4. 3D printed model of prototype mouth part.

3. RESULTS AND DISCUSSION

3.1 Effects of Materials Properties on von Mises stress.

The von Mises stress values, which signify the peak equivalent stress experienced by the material, were examined for both ABS and PLA materials across varying loads. The contour color pattern for von Mises stress when subjected to the loading of 10N, 50N and 100N for ABS material as shown in Figure 5 and PLA material as shown in Figure 6.

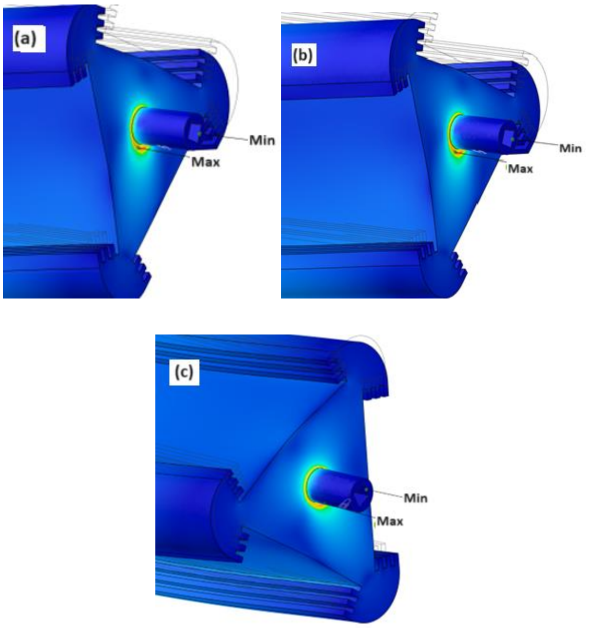

Fig. 5. Contour color pattern for von Mises stress when subjected to the loading for ABS material (a) 10N (b) 50N (c) 100N.

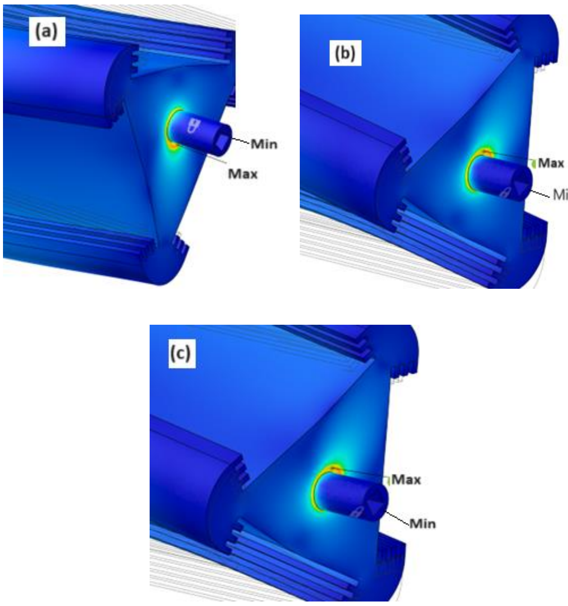

Fig. 6. Contour color pattern for von Mises stress when subjected to the loading for PLA material (a) 10N (b) 50N (c) 100N.

Figure 7 shown an upward trend in stress values was observed as the applied load increased. Specifically, for the 10N load, both materials exhibited stress values well below 1 MPa, with ABS measuring 0.4549 MPa and PLA measuring 0.4707 MPa. Upon escalation to 50N, ABS demonstrated a maximum von Mises stress of 2.274 MPa, while PLA exhibited 2.353 MPa, indicating that PLA incurred slightly higher stress at this load level. Notably, even under the heaviest load of 100N, both materials displayed maximum stress values lower than 5 MPa. ABS registered 4.549 MPa, and PLA showed 4.707 MPa. This data substantiates the resilience of both ABS and PLA materials, withstanding the applied loads without significant deformity or risk of failure. It's worth noting that the observed difference in stress levels between ABS and PLA across various loads is minimal, implying comparable mechanical performance under these conditions. Overall, these findings reinforce the feasibility of both materials for constructing the eye examination device, with PLA showcasing a slightly higher maximum stress yet still well within safe limits for its intended application.

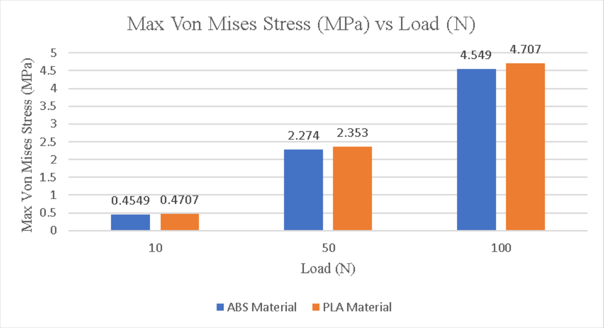

Fig. 7. Max von Mises stress (MPa) vs load (N) for ABS material and PLA material.

3.2 Effects of Materials Properties on Total Deformation.

The displacement values represent the extent of deformation experienced by the fundus image frame due to the applied loads. The contour color pattern for maximum displacement when subjected to the loading of 10N, 50N and 100N for ABS material as shown in Figure 8 and PLA material as shown in Figure 9.

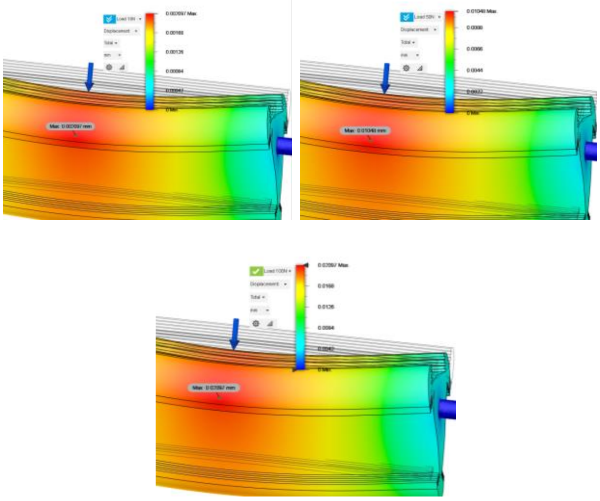

Fig. 8. Contour color pattern for maximum displacement when subjected to the loading for ABS material (a) 10N (b) 50N (c) 100N

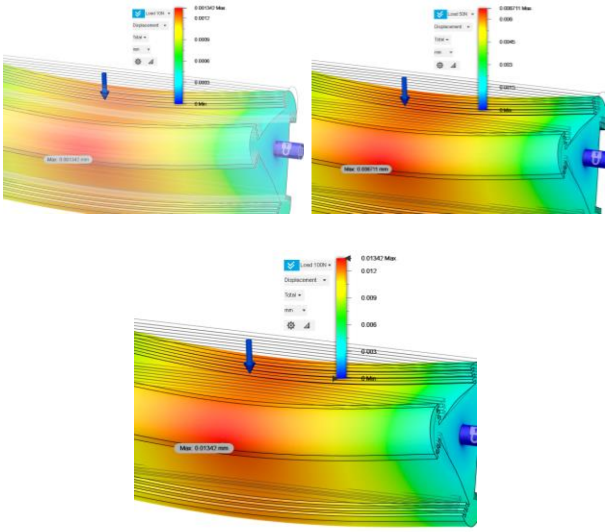

Fig. 9. Contour color pattern for maximum displacement when subjected to the loading for PLA material (a) 10N (b) 50N (c) 100N.

Similar to the von Mises stress, the displacement increases with increasing load for both ABS and PLA. At 10N, the maximum displacement is less than 0.003mm for both materials, indicating minimal deformation. As the load increases to 50N and 100N, the displacement also increases, but it remains relatively small, with the maximum displacement less than 0.021mm for both materials. Comparing ABS and PLA, ABS generally displays slightly higher displacements, likely due to its higher flexibility and elongation capabilities. However, both materials demonstrate excellent performance in maintaining the structural integrity of the fundus image frame under the applied loads. Figure 10 shows the result of the deformation.

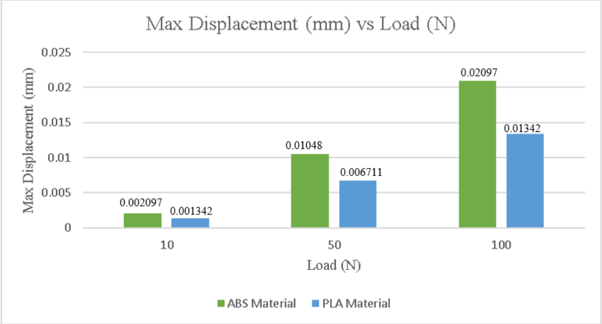

Fig. 10. Max displacement (mm) vs load (N) for ABS material and PLA material.

3.3 3D Printed Model of Ophthalmology Eye Examination Device

The integration of mechanisms within the head proved to be successful, with all mechanisms demonstrating effective functionality. This underscores the success of the design and assembly processes, confirming the functional viability of the 3D printed eye examination device.

All the parts of the head and mechanism that have been printed have been assembled. The head part assembles with joint and slot holes that have been made on the parts. Next, the eyeball was inserted into the spur gear and the spur gear was put on the top of the mouth part surface and connected with the rack gear. Figure 11 shows the assembly of the mouth, rack gear, spur gear, and eyeball parts.

Fig. 11. Assembly of the mouth, rack gear, spur gear, and eyeball parts.

4. CONCLUSION

In conclusion, the development of an affordable and advanced eye examination device for ophthalmology students has successfully utilized modern technologies like 3D printing. This device overcomes the limitations of existing options, providing a more interactive and practical learning experience. By incorporating a mechanism to simulate the eye's momement, students gain a deeper understanding of ophthalmoscopy. Accurate representation of real human eyes is achieved through 3D scanning and modeling, while 3D printing enables customization. The ergonomic design and user-friendly interface contribute to the ease of use and student confidence in performing ophthalmoscopy examinations. Overall, this device enhances ophthalmology education by offering practical experience and skill development in detecting and diagnosing eye diseases, showcasing the potential for further advancements in the field.

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