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Finite Element Analysis and Comfort Assessment Conducted on the Visual Aid Design for Monocular Vision Patients

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ABSTRACT

Abstract — Monocular visual impairment is one of the most overlooked impairments globally. Focusing on the comfort of monocular visually impaired individuals, finite element analysis and comfort assessment of the design concept of visual aid (Utility Innovation number UI20190059) were conducted in this study. Using this visual aid, users are expected to experience increased field of vision and depth in their vision. The technology behind this is similar to image classification techniques[1]. Basically, the underlying forces in the design concept of the visual aid are forces exerted from the attached hardware (e.g. camera, LCD screen, and microcontrollers). SOLIDWORKS® Simulation 2019 was used to perform Von-Mises stress analysis, Von-Mises strain analysis, and displacement analysis, where the attributes of ABS polycarbonate served as the benchmark for the obtained results. Additionally, a survey that involved real subjects was conducted. The respondents were required to evaluate the overall comfort, weight on nose bridge, and aesthetic design of a 3D printed model that replicates the physical geometries of the visual aid from 1 (least comfortable) to 10 (most comfortable). Based on the obtained results, this study successfully proved the feasibility and practicability of the visual aid (Utility Innovation number UI20190059) for monocular visually impaired individuals.

Key words : Assessment, Patients, Visual, Analysis

1. INTRODUCTION

The development of visual aid (Utility Innovation number UI20190059) for the monocular visually impaired population has received understated attention in research[2] as this particular impairment only affects a small group of visually impaired individuals. A monocular visually impaired individual has vision but only on one eye. The preliminary review on the current practices that address monocular visual impairment revealed the need to develop a visual aid that increases the users' field of vision and depth.

This study focused on the failure analysis on the prototype design of the developed visual aid (Utility Innovation number UI20190059). The failure analysis provides a better understanding of the limitations of the proposed design. In this case, static analysis was deemed pivotal—the critical stresses and strains of the design under static condition were scrutinised in detail to ensure its novelty and industrial applicability uphold or even surpass key criteria of the industrial standards considering that the developed design was for the training use at Tun Hussein Onn National Eye Hospital in Petaling Jaya.

Using SOLIDWORKS® Simulation, Von-Mises stress analysis, Von-Mises strain analysis, and displacement analysis were conducted. This study aimed to assess the feasibility and practicability of visual aid (Utility Innovation number UI20190059) for monocular visually impaired individuals. This paper serves as a supporting technical document for the IP (Utility Innovation) application of UI20190059[2].

2. LITERATURE REVIEW

A visual aid was developed for monocular visually impaired patients. An IP application for utility innovation under the Intellectual Property Commission of Malaysia has been filed for the developed visual aid (Utility Innovation number UI20190059). The application also includes the specific design and functionality of the developed visual aid.

2.1 Design of Visual Aid (ID: UI 20190059)

Using SOLIDWORKS® Simulation 2018 Premium, the visual aid was meticulously designed according to the dimensions of a camera, microprocessor, and screen. As shown in Figure 1, the visual aid is basically a pair of spectacles with two cameras, a microprocessor, and a screen. Both cameras are fixed above the frame of the spectacles. The distance between the installed wide-angle 160-degree cameras is 30 mm. The 3.5-inch Raspberry Pi 3B+ display, which is connected to the visual aid using wire, is provided separately as a portable device that can be placed in the user's pocket. Meanwhile, the screen is another important part of the design. It displays the actual stereo depth image that is perceived from the installed cameras and processed by the onboard microprocessor system to compressor the videos obtained [3].

The design in Figure 1 consists of a spectacle with the screen, cameras and the microprocessor, the cameras are embedded at the top of the spectacle. The cameras are also spaced at 30mm apart from each other. The 3.5-inch Raspberry Pi 3B+ is provided separately as a portable device that can be located in the pocket of the user with a wire connecting to the visual aid. The cameras used in this design is a wide-angle 160-degree camera [4].

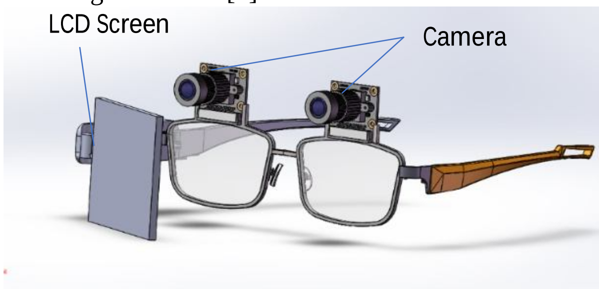


Figure 1: Visual Aid Design Concept

The screen is the vital part of the design, as it displays the actual stereo depth image that is perceived from the cameras and processed by the microprocessor on board[5]. The screen is attached to the frame of the visual aid by a hinge design which is shown in Figure 2.

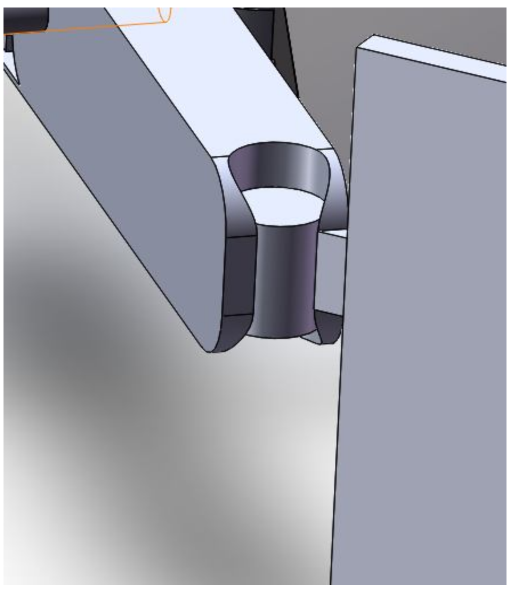


Figure 2: The design has a revolutionized hinge design which allows the screen to rotate for easy portability

3. METHODOLOGY

3.1 Comfort Assessment

It is pivotal to design a comfortable and practical visual aid for monocular visually impaired individuals [6].Hence, a comfort assessment should be performed, especially on the weight, material used, and the overall design of the visual aid [7]. Referring to the study on the weight distributed by nose pads by Walsh et al., the recommended nose-pad contact area of a spectacle frame that weighs up to 25 g should not exceed 200 mm^2 whereas the recommended nose-pad contact area of a spectacle frame that weighs over 25 g should be at least 250 mm^2[8]. Following the determination of these key factors in static analysis using SOLIDWORKS® Simulation 2018, comfort assessment was conducted via a survey that involved individuals with low vision. A total of 10 respondents from 50 people of low vision patient population per day participated in the survey. They were required to evaluate the overall comfort, weight on the nose bridge, and aesthetic design of a 3D printed model that replicates the physical geometries of the visual aid from 1 (least comfortable) to 10 (most comfortable).

3.2 Static Study

The static analysis provides essential insights on the critical stress-strain points and other force components that act on an object under a certain external load. As for the present study, the static analysis was conducted using SOLIDWORKS® Simulation, which is part of an add-in programme in SOLIDWORKS® Simulation 2018 Premium. Table 1 presents the details of the mesh analysis (preprocessing for static analysis). Meanwhile, Figure 3 presents the orthographic view of the design concept whereas Figure 4 presents the exploded view of the design concept.

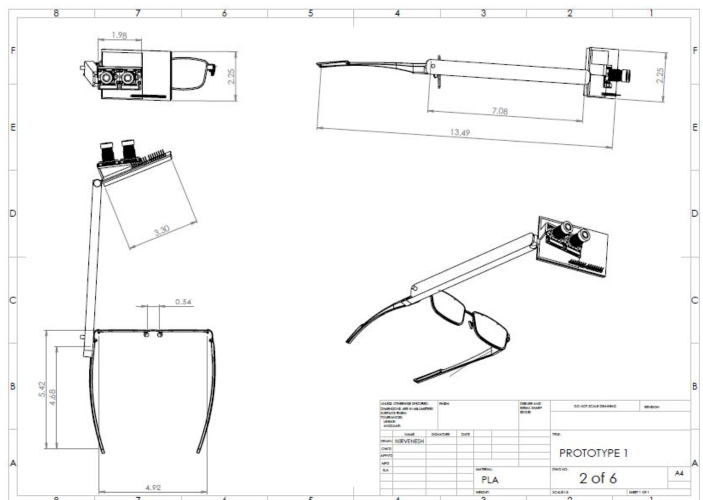


Figure 3: Orthographic drawing of design concept

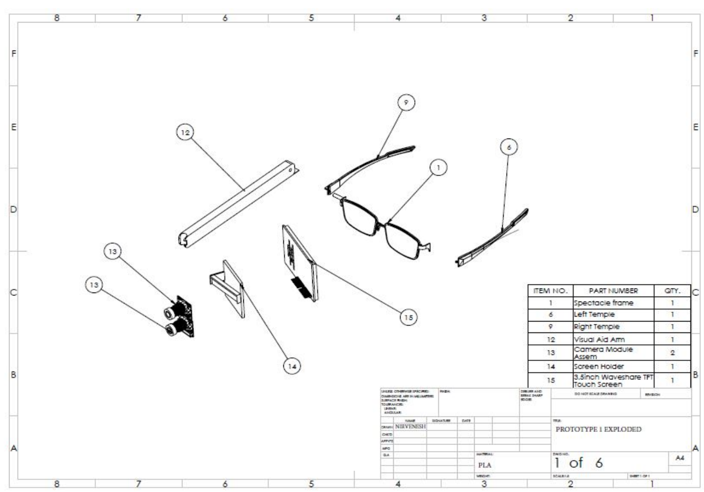


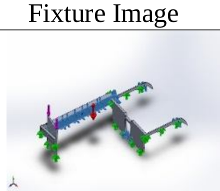
Figure 4: Exploded drawing of design concept

Table 1: Mesh analysis of the design concept

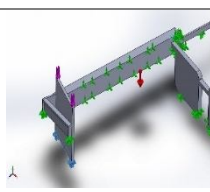
Total nodes	1115716
Total elements	726279
Maximum aspect ratio	152.07
Elements with aspect ratio of less than 3%	98.5%
Elements with aspect ratio of more than 10%	0.0202%

Figure 5 : Mesh Image of Design Concept

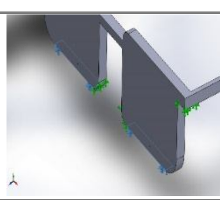
Table 2: Fixtures Applied on Design Concept

Fixture name	Fixture Image	Fixture Details
Fixed-1		5 face(s) Fixed Geometry

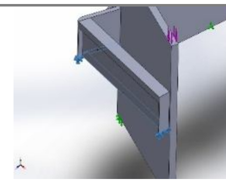
Resultant Forces				
Components	X	Y	Z	Resultant
Reaction force(N)	**0.000273586**	**0.414493**	**-0.00309878**	**0.414505**

Fixture name	Fixture Image	Fixture Details
Fixed-2		1 edge(s), 1 face(s) Fixed Geometry

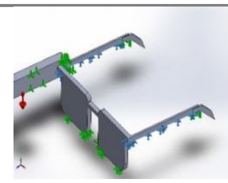
Resultant Forces				
Components	X	Y	Z	Resultant
Reaction force(N)	**-0.00913319**	**0.51055**	**-0.0241037**	**0.5112**

Fixture name	Fixture Image	Fixture Details
Fixed-3		2 face(s) Fixed Geometry

Resultant Forces				
Components	X	Y	Z	Resultant
Reaction force(N)	**0.000777361**	**0.165315**	**-0.00281183**	**0.16534**

Fixture name	Fixture Image	Fixture Details
Fixed-5		2 face(s) Fixed Geometry

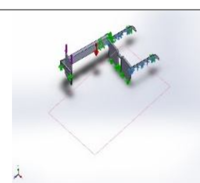
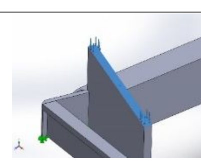
Resultant Forces				
Components	X	Y	Z	Resultant
Reaction force(N)	**0.00215938**	**0.108642**	**0.00160813**	**0.108675**

Fixture name	Fixture Image	Fixture Details
Fixed-6		2 face(s) Fixed Geometry

Resultant Forces				
Components	X	Y	Z	Resultant
Reaction force(N)	**0.00098327**	**0.04085**	**0.00637382**	**0.041356**

3. **Loads**

Table 3 : Loads Applied on Design concept

Load name	Load Image	Load Details
Gravity-1		Value: **9.81 ms^{-2}**
Force-1		**Type: Apply normal force** **Value: 0.48 N**

ABS polycarbonate or also widely known as PC-ABS was used as a control in the testing of the design concept. This high-graded plastic is the most commonly used material in the manufacturing industry due to the superior strength and heat resistivity of polycarbonate and the flexibility of ABS [9]. In addition, the high endurance and resilience of PC-ABS, unlike the regular polycarbonate, contribute to its extensive use in the automotive and telecommunications industry. Besides that, PC-ABS is also widely used in various applications such as power-tool prototyping and industrial equipment manufacturing because this material can mimic the material properties of the final product [10].

Table 4: Properties of ABS polycarbonate

Material	PC-ABS
Model	Linear elastic isotropic
Tensile strength	4×10^7 N/m^2
Elastic modulus	2.41×10^9 N/m^2
Poisson's ratio	0.3897
Mass density	1070 kg/m^3
Shear modulus	8.622×10^8 N/m^2

4. RESULTS, ANALYSIS AND DISCUSSION

4.1 Comfort Assessment

Table 5presents the volumetric properties of the design concept.

Table 5: Volumetric properties of Design Concept 1

Mass	0.0532860 kg
Volume	1.05875×10^{-5} m^2
Density	1070 kg/m^3
Weight	0.52273566 N

The visual aid weighs at 53 g, which exceeds the mark guideline of 25 g by Walsh et al. However, the nose-pad contact area (273 mm^2) exceeds the recommended nose-pad contact area of 250 mm^2. As shown in Table 6, all participating respondents were monocular visually impaired. In particular, most of the respondents were diagnosed with amblyopia. Overall, the design concept scored an average comfort rating of 7 (1: least comfortable; 10: most comfortable). In other words, the users are generally comfortable with the overall comfort and weight of the visual aid despite the weight of the visual aid. These results indicate that the nose-pad contact area equally distributes the weight of the visual aid on the nose bridge of users.

Table 6: Results of comfort assessment

Respondent	Comfort rating (1-10)	Type of visual impairment
1	6	Amblyopia
2	7	Amblyopia
3	5	Amblyopia
4	8	Trauma (Vehicle accident)
5	8	Glaucoma
6	7	Amblyopia
7	6	Glaucoma
8	8	Amblyopia
9	9	Amblyopia
10	8	Glaucoma

From the survey that was conducted, all the respondents of the survey were of monocular visual impairment. Most of the respondents who have participated in the survey were diagnosed with amblyopia. The survey points out an average comfort rating of 7. With this it can be deduced that most of the respondents were comfortable with the weight of the visual aid and the comfort that is in accordance with. This is due to the accommodation of the nose pads surface area which distributes the weight of the visual aid equally on the nose bridge of the patient.

4.2 Static Analysis

4.2.1 DESIGN CONCEPT 1

The obtained results of Von-Mises stress analysis demonstrated the success of the design concept. Its tensile strength did not exceed the limit of 4.00×10^7 N/m^2. The design concept experienced maximum stress of 8.823×10^6 N/m^2 and maximum strain of 2.794×10^{-4} The recorded values of strain suggest a very low level of strain. Besides that, the maximum displacement (3.098×10^{-1}mm) is relatively low. In other words, the displacement is safe within the limit, as it does not exceed its yield strength of 4.00×10^7 N/m^2 These results proved that the design concept does not undergo plastic deformation.

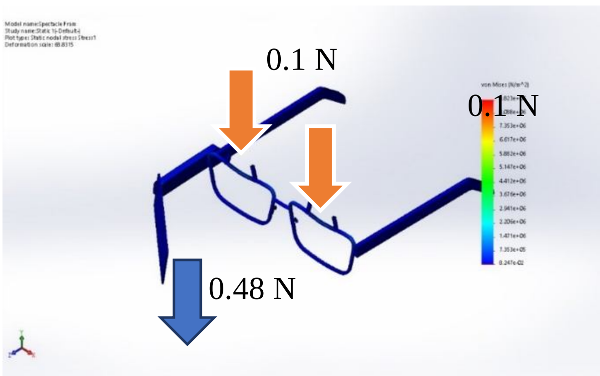


Figure 6: Fringe Diagram of Stress Analysis with Load

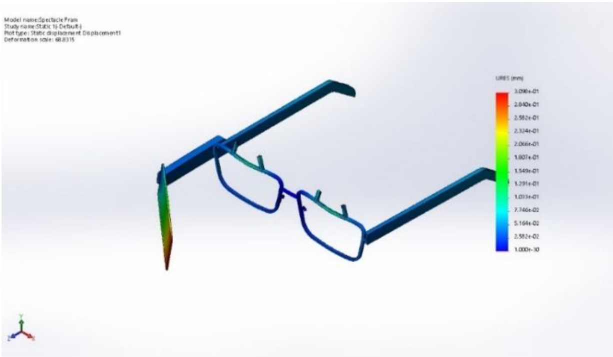


Figure 7: Fringe Diagram of Displacement Analysis

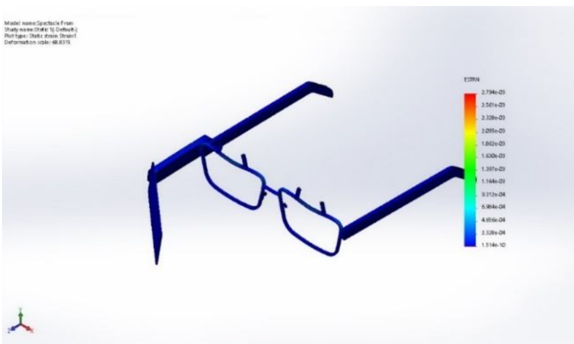


Figure 8: Fringe Diagram of Strain Analysis

5. CONCLUSION

Monocular visually impaired individuals have vision on one eye and limited vision on the other eye. A visual aid can substantially help them to increase their field of vision and overcome the challenges of depth perception. Focusing on the developed visual aid (Utility Innovation number UI20190059), the finite element analysis and comfort assessment were conducted in this study. The design concept and static analysis were performed using SOLIDWORKS® Simulation 2018. The design concept was simulated based on the actual forces like the cameras, onboard microprocessor system, and LCD screen. The comfort assessment involved monocular visually impaired individuals who were mostly diagnosed with amblyopia. The survey revealed an average comfort rating of 7, which can be explained by the nose-pad surface area of 273 mm^2 considering that the spectacle frame weighs more than 25 g. Additionally, the obtained results of static analysis revealed that the design concept did not exceed the corresponding limit of both stress and strain of the design concept. Thus, it can be assumed that the design concept does not undergo plastic deformation under extreme conditions. Conclusively, this study successfully proved the feasibility and practicability of the visual aid (Utility Innovation number UI20190059) for monocular visually impaired individuals.

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