Jurnal Rekayasa Mesin
p-ISSN: 1411-6863, e-ISSN: 2540-7678
Vol.20, No.2, August **2025**, hal. 265-0270

Prosthetic Foot Mold Making with Photogrammetry Based Reverse Engineering Method

Muhammad Arif Hidayat, Wahyu Dwi Lestari*
Mechanical Engineering Study Program, Faculty of Engineering and Science,
Veteran National Development University of East Java
Jl.Raya Rungkut Madya, Gunung Anyar, Surabaya
*E-mail: wahyu.dwi.tm@upnjatim.ac.*id*

Submitted: 25-02-2025; Accepted: 30-08-2025; Published: 31-08-2025

Abstract

Prosthetic foot mold making is a crucial stage in the production of prosthetic feet that are in accordance with the anatomy and user needs. This research aims to develop a method for making prosthetic foot mold using a reverse engineering approach with photogrammetry techniques. The process begins with scanning the sole of the foot using photogrammetry methods to obtain a three dimensional model. The scanned model is then converted into a CAD design which is used as the basis for mold making. The mold design was made by considering ergonomic aspects and ease of manufacturing in the next stage. The results showed that the average deviation was within the range of ±0.65 mm or 0.42%, with a maximum deviation of 1.42%. This method is capable of producing precise casts that match the geometry of the original foot. With this approach, it is expected to improve the quality and customization of prosthetic products in the future.

Keywords: *CAD design; Photogrammetry; Prosthetic foot mold; Reverse engineering.*

Abstrak

Pembuatan cetakan telapak kaki prostetik merupakan tahapan krusial dalam produksi kaki palsu yang sesuai dengan anatomi dan kebutuhan pengguna. Penelitian ini bertujuan untuk mengembangkan metode pembuatan cetakan telapak kaki prostetik menggunakan pendekatan reverse engineering dengan teknik photogrammetry. Proses dimulai dengan pemindaian telapak kaki menggunakan metode photogrammetry untuk memperoleh model tiga dimensi. Model hasil pemindaian kemudian dikonversi menjadi desain CAD yang digunakan sebagai dasar dalam pembuatan cetakan. Desain cetakan dibuat dengan mempertimbangkan aspek ergonomi dan kemudahan dalam proses manufaktur di tahap selanjutnya. Hasil penelitian menunjukkan bahwa tingkat deviasi rata-rata berada dalam rentang ±0,65 mm atau 0,42 %, dan paling tinggi 1,42%. Metode ini mampu menghasilkan cetakan yang presisi dan sesuai dengan geometri telapak kaki asli. Dengan pendekatan ini, diharapkan dapat meningkatkan kualitas dan kustomisasi produk prostetik di masa depan.

Kata kunci: Desain CAD; Photogrammetry; Cetakan telapak kaki prostetik; Reverse engineering.

1. Introduction

Prosthetics is one of the fastest growing technologies in the field of biomedical engineering to improve the quality of life of people with disabilities [1]. Prosthetic foot molds in prosthetic foot manufacturing have an important role in determining comfort and fit for the user [2]. Conventional techniques in mold making often lack precision and take a long time [3]. Therefore, a photogrammetry-based reverse engineering approach was introduced as a solution to improve efficiency and accuracy in mold manufacturing [4].

Photogrammetry, as an image-based three dimensional modeling technique, enables the acquisition of foot geometry data with a high degree of accuracy [5]. Through this technique, a digital model of the foot can be created more quickly and precisely, ultimately improving prosthetic fit and comfort for the user [6][7]. Research shows that the use of photogrammetry in prosthetic design can produce more accurate models and reduce reliance on manual molding techniques that require specialized skills and long lead times [8][9]. In addition, another study showed that 3D scanning can speed up the mold-making process, thereby reducing the time required to produce a suitable prosthetic [10].

The accuracy of a foot scan using photogrammetry can be evaluated through comparative analysis between the resulting model and the physical size of the foot. Previous research has shown that 3D scanning can provide more consistent and repeatable results than traditional methods, which are often affected by human factors [11]. In addition, the development of CAD design models based on the scan results allows for better customization to the individual needs of the user, thus improving the comfort and functionality of the prosthetic [12].

p-ISSN: 1411-6863, e-ISSN: 2540-7678
Vol.20|No.2|265-270|August|2025

Based on these problems, this research aims to develop a method for making prosthetic foot molds using a photogrammetry based reverse engineering approach. The main objectives of this research are: (1) evaluate the accuracy of the foot scan using photogrammetry techniques, (2) develop a CAD design model based on the scan results, and (3) design a mold that is ready to be used in the prosthetic manufacturing stage. The result of this research is expected to be a more efficient and accurate method in prosthetic mold making that can be widely applied in the healthcare and biomedical engineering industries.

2. Material and Method

This research was carried out in several main stages as shown in the flowchart in figure 1.

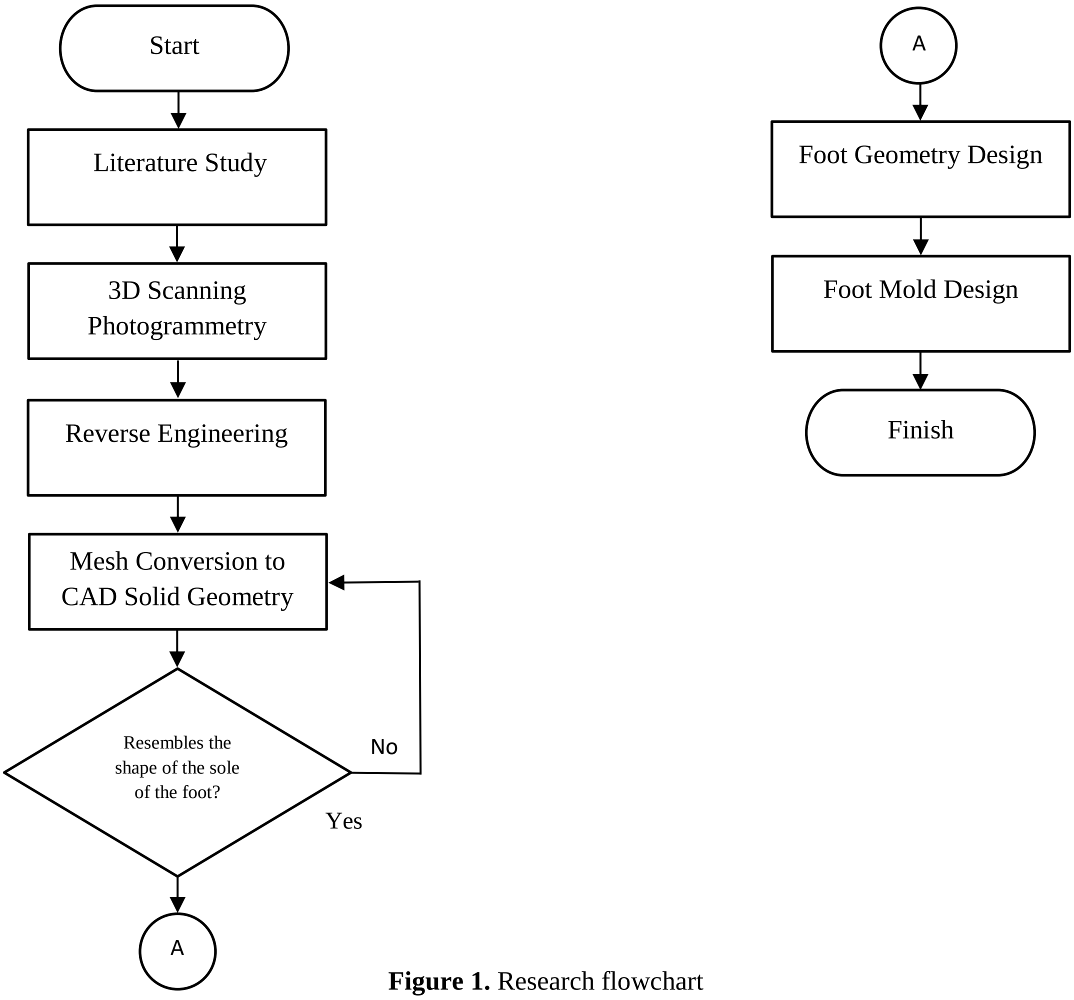

Figure 1. Research flowchart

2.1 Sole of the foot Scanning with Photogrammetry

The process begins with a scan of the sole of the foot using the photogrammetry method. This technique utilizes images from various angles to build an accurate three-dimensional model. Specialized software was used to process the images and generate a digital model of the sole. The foot that was scanned was a commercial foot prosthesis with the brand Ottobock in Figure 2. And the scanning process used the Einstar 3D scanner in Figure 3.

Figure 2. Ottobock Foot Prosthesis

Figure 3. Einstar 3D scanner

2.2 CAD Modeling

Once the three-dimensional model is obtained, the next step is to convert the scan into a CAD design. This process is carried out with CAD software to ensure that the resulting model matches the required design specifications. Modification and refinement of the model is done to remove imperfections in the scans. The CAD modeling process is schematically shown in Figure 4.

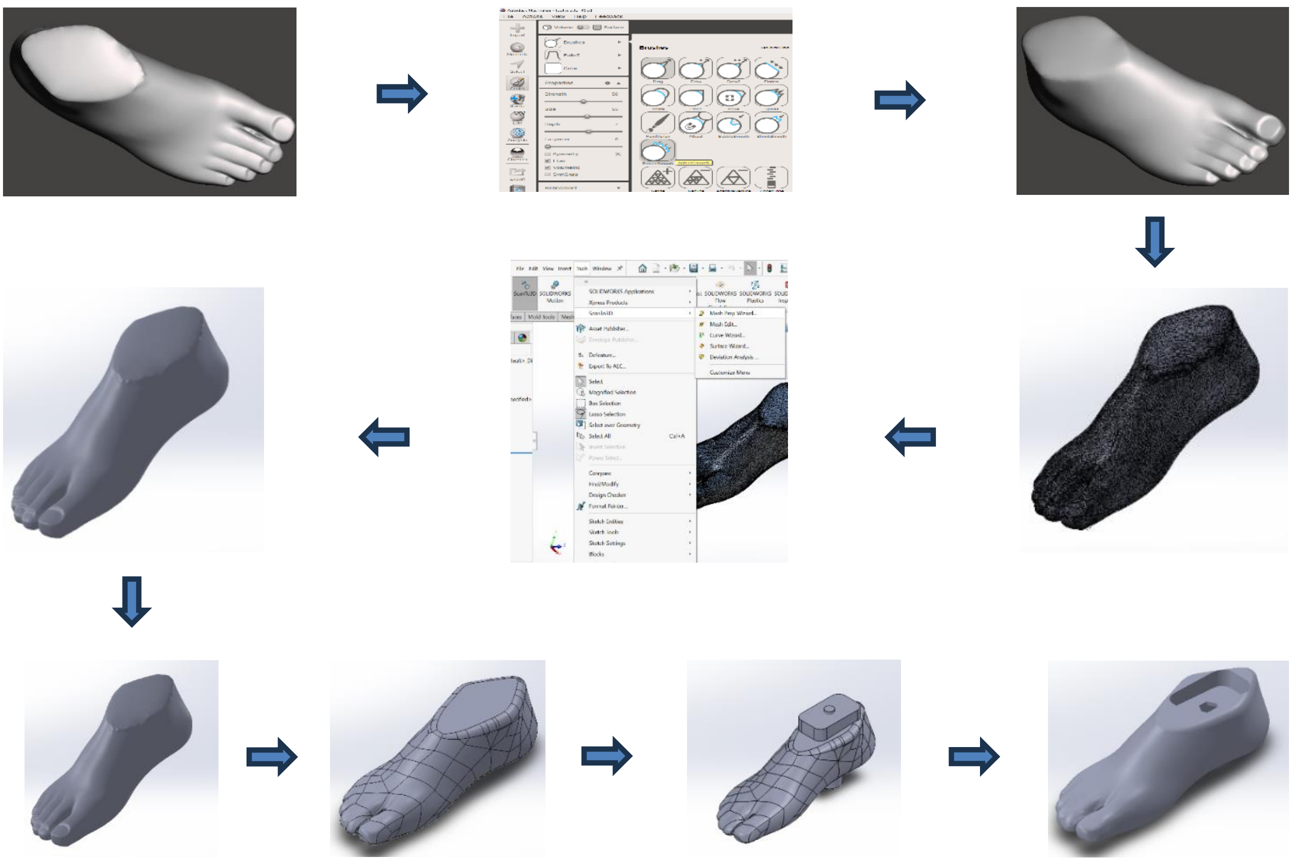

Figure 4. Schematic CAD Modeling Process

2.3 Mold Design

Based on the CAD design of the foot, a mold was designed using Mastercam 2024 and Solidworks 2020 software. The mold design considers factors such as ergonomics, ease of manufacture, and efficiency in the manufacturing process at a later stage. The foot prosthesis mold design produced in this study is shown in Figure 5.

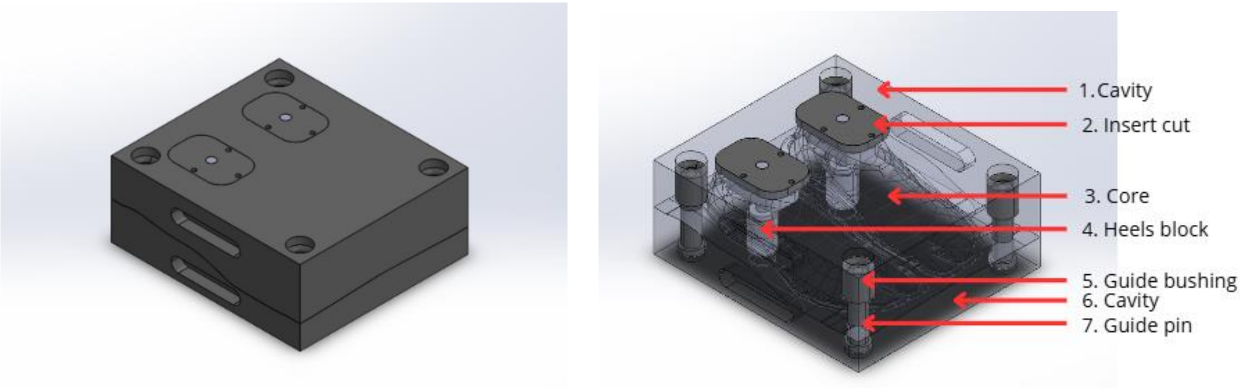

Figure 5. Foot Prosthesis Mold Design

The dimensions of the prosthetic foot mold molding in this study are, Length 275 mm x Width 245 mm x Height 110 mm with the following parts.

1. Cavity which is the part of the mold that forms the outside of the product. There are two cavity in the mold shown in number 1 and number 6.
2. Insert cut is the part that will perforate the core in the upper ankle of the leg during the product formation process. Insert cut shown in number 2.
3. Core is the core part of the mold that forms the inner chamber or cavity of the final product. Core is the part that makes up the prosthetic foot product, shown in number 3.
4. Heels block, This molding design serves to perforate the core at the bottom of the foot during the product formation process. Shown in number 4.
5. Guide bushing is a hole-shaped bushing or sleeve that serves as an entry point for the guide pin, ensuring that the two mold halves (top and bottom) remain aligned and precise when joined together. Shown at number 5. In this mold there are 4 guide pin and guide bushing.
6. Guide pin is a component used to ensure that the two mold halves (top and bottom) remain precisely aligned during the molding process. Guide pin help prevent shifting or misalignment between the two mold halves, so that the resulting mold has precise dimensions according to the desired design. Shown in number 7.

3. Results and Discussion

The results show that the photogrammetry method can produce a three-dimensional model of the sole of the foot with a high degree of accuracy. Scans were taken from various angles, resulting in a detailed model that matched the original shape of the foot. Comparison between the digital model and the original foot geometry showed minimal deviation, indicating that photogrammetry is a reliable method for foot geometry data acquisition.

3.1 3D Model Accuracy Evaluation

The accuracy evaluation of the 3D model of the foot prosthesis produced was performed by comparing the dimensions of the digital model with those of the real object. Measurements were taken on several key parameters, including foot length, foot width, and foot arch height. The analysis results showed that the average deviation rate was within the range of ±0.65 mm, indicating that the method has high accuracy.

Table 1. 3D Model Accuracy Evaluation

No.	Parameters	Original Foot Dimensions (mm)	CAD Model Dimensions (mm)	Deviation (mm)
1.	Foot length	240	239,20	0,80
2.	Forefoot length	170,90	170,37	0,53
3.	Foot length to little finger	208,80	205,86	2,97

No.	Parameters	Original Foot Dimensions (mm)	CAD Model Dimensions (mm)	Deviation (mm)
4.	Foot width	85,65	85,62	0,3
5.	Foot stalk width	69,62	69,45	0,17
6.	Ankle Height	59,49	59,37	0,12
7.	Midfoot height	66,38	66,25	0,13
8.	Horizontal distance of ankle stalk	52,48	52,33	0,15

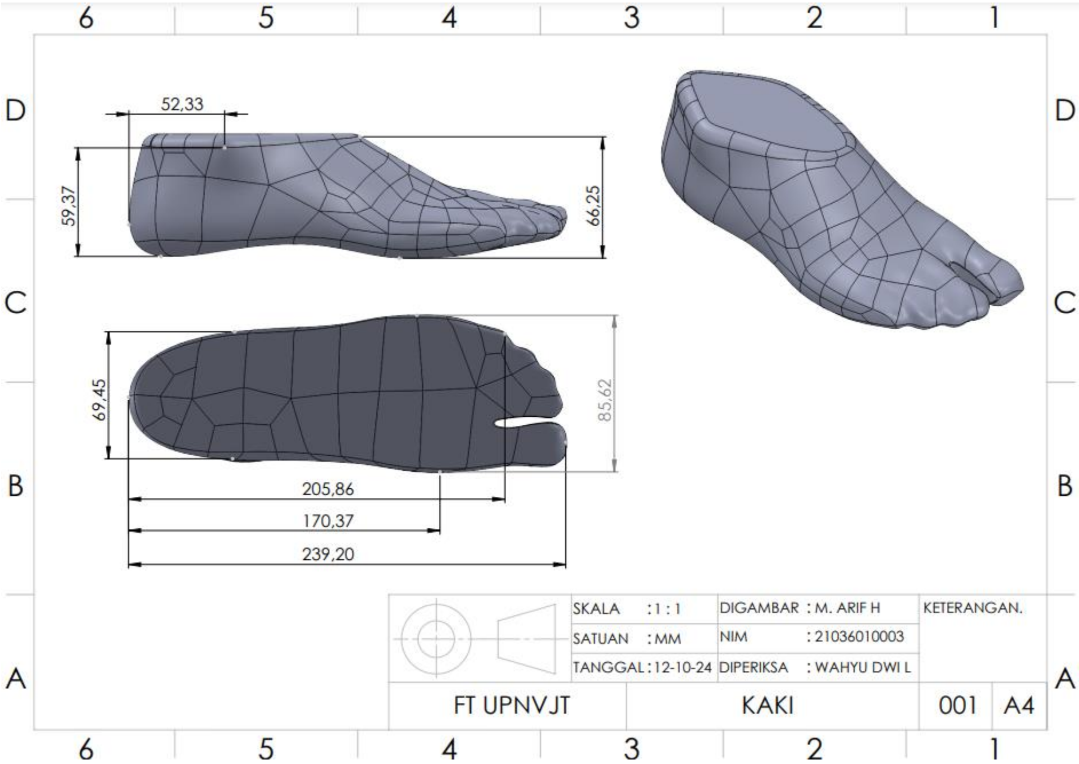

Figure 6. Core Design of Foot Prosthesis

3.2 Advantages and Challenges of Photogrammetry Method

Photogrammetry has an important role in the manufacture of foot prosthesis with several aspects of advantages and limitations that must be known. The advantage of photogrammetry is high accuracy for measurement, of course, it must be accompanied by additional size indicators in taking photos [13]. Compared to conventional methods, photogrammetry allows the body shape mapping process to be done faster, saving time in design and production. Moreover, the resulting model can be easily modified and customized to enhance the comfort and performance of the prosthetic according to individual needs. In addition, the advantage of photogrammetry is that the devices used are quite easy to obtain and use, and easy to carry.

The first limitation of photogrammetry is that to produce a fast and good process, hardware such as cameras and computers that have high specifications and are expensive are required. Cameras used for photogrammetry vary widely, cameras priced below 10 million can still be used. Some researchers have innovated to use smartphones as a substitute for cameras so that costs can be cheaper [14]. Software that is easy and quick to use is also quite expensive nowadays, such as Agisoft. The good news is that technical learning of photogrammetry can be quite affordable and even free and widespread on the internet [15]

4. Conclusion

This research shows that a photogrammetry based reverse engineering approach can be effectively used in the design of prosthetic foot molds. The results of the analysis show that the average deviation rate is in the range of ±0.65 mm or 0.42%, with a maximum of 1.42%. This method provides high accuracy and ease in making molds ready for the next manufacturing stage. The implementation of this technology is expected to contribute to the development of more adaptive and affordable prosthetics for users.

References

[1] Prastiwi, D., Lestari, W., Utami, R. T., Rinarto, N. D., Chabibah, N., Fitriyani, N. L. L., ... & Al Musyahadah, U. S., Pengantar Biomedik Panduan Komprehensif; 2023.

[2] Gujarathi, I. A., Zahabi, M., Pei, Z. J., & Patterson, A. E., Decision-Making Framework for Customized Additively-Manufactured Lower-Limb Prosthetics. 2024 August; p. 181–207.

[3] Pereira, T., Kennedy, J. V., & Potgieter, J., A comparison of traditional manufacturing vs additive manufacturing, the best method for the job. Procedia Manufacturing. 2019; 30. p. 11–18.

[4] Silva, R., Silva, B., Fernandes, C., Morouço, P., Alves, N., & Veloso, A., A Review on 3D Scanners Studies for Producing Customized Orthoses. Sensors. 2024 February; 24(5). p. 1-19.

[5] Istenič, K., Gracias, N., Arnaubec, A., Escartín, J., & Garcia, R., Scale accuracy evaluation of image-based 3D reconstruction strategies using laser photogrammetry. Remote Sens. 2019 July; 11(18). p. 1-32.

[6] Barrios-Muriel, J., Romero-Sánchez, F., Alonso-Sánchez, F. J., & Salgado, D. R., Advances in orthotic and prosthetic manufacturing: A technology review. Materials (Basel). 2020 January; 13(2). p.1-15.

[7] Al-Kharaz, A. A. I., 3D Photogrammetric Images To Evaluate Foot Morphology And Ankle Kinematic During Gait Of Middle Eastern Adults. Australia University of Southern Queensland. 2021. p.163.

[8] Cullen, S., Mackay, R., Mohagheghi, A., & Du, X., The use of smartphone photogrammetry to digitise transtibial sockets: Optimisation of method and quantitative evaluation of suitability. Sensors. 2021 December; 21(24), p. 1-16.

[9] Ismail, R., Taqriban, R. B., Ariyanto, M., Atmaja, A. T., Sugiyanto, Caesarendra, W., ... & Glowacz, W., Affordable and Faster Transradial Prosthetic Socket Production Using Photogrammetry and 3D Printing. lectronics. 2020 September; 9(9), p. 1-11.

[10] Dickinson, A. S., Donovan-Hall, M. K., Kheng, S., Bou, K., Tech, A., Steer, J. W., ... & Worsley, P. R., Selecting Appropriate 3D Scanning Technologies for Prosthetic Socket Design and Transtibial Residual Limb Shape Characterisation. Journal of Prosthetics and Orthotics. 2022 January; 34(1). p.33-43.

[11] Sanz-Pena, S. M. Arachchi, N. Curtis-Woodcock, P. Silva, A. H. McGregor, and N. Newell., Obtaining Patient Torso Geometry for the Design of Scoliosis Braces. A Study of the Accuracy and Repeatability of Handheld 3D Scanners. Prosthetics and Orthotics International. 2022 August; 46(4). p. e374–e382.

[12] Vasiliadis, A. V., Koukoulias, N., & Katakalos, K., From Three-Dimensional (3d)- To 6d-Printing Technology in Orthopedics: Science Fiction or Scientific Reality. J. Funct. Biomater. 2022 Juli; 13(3). p. 1-16.

[13] Medina, J. J., Maley, J. M., Sannapareddy, S., Medina, N. N., Gilman, C. M., & McCormack, J. E., A rapid and cost-effective pipeline for digitization of museum specimens with 3D photogrammetry. PLoS ONE. 2020 August; 15(8). p.1–14.

[14] Priyambodo, D. Y., Aplikasi Fotogrametri untuk Pemeriksaan Kerangka. Plexus Medical Journal, 2022 August; 1(4). p.122–129.

[15] Dabove, P., Grasso, N., & Piras, M., Smartphone-based photogrammetry for the 3D modeling of a geomorphological structure. Applied Sciences (Switzerland*)*, 2019 September; *9*(18). p.1-20.