Dimensional accuracy of Melaka historical artifact produced from additive manufacturing and reverse engineering systems

Syahibudil Ikhwan Abdul Kudus[1,2], Kerk Zi Ling[1], Hambali Boejang[1], Mohammad Rafi Omar[1,2], Mohd Idain Fahmy Rosley[1,2], Shafizal Mat[2,3,*]

[1] Fakulti Teknologi Kejuruteraan Mekanikal & Pembuatan, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia
[2] Centre for Advanced Research on Energy, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia
[3] Fakulti Kejuruteraan Mekanikal, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia

[*] Corresponding e-mail: shafizal@utem.edu.my

Keywords: additive manufacturing, reverse engineering, dimensional accuracy

ABSTRACT – The purpose of this study is to reproduce flintlock Dutch gun of Melaka historical artifact using reverse engineering and additive manufacturing technology and compare the dimensional accuracy of the 3D printed component produced from two different additive manufacturing and reverse engineering systems. The dimensional accuracy was measured using digital Vernier caliper at eight selected areas. The dimensional accuracy of the 3D printed replica was compared based on the range of percentage of error. The result indicates that a combination of Solutionix REXSCAN 3D scanner and laser sintering machine produced a high dimensional accuracy, smooth surface finishing, and fine detail 3D printed historical artifact.

1. INTRODUCTION

Additive manufacturing (AM) and reverse engineering (RE) applications have played an important role in the field of preservation, conservation, and reconstruction of historical artifacts in recent years. The availability of these technologies has paved the way to a new era of historical artifacts: a reproduction of replicas that subjected to environmental degradation, burglary, and man-made sabotage [1, 2].

RE allows the user to obtain high precision 3D models, both digital and physical objects [1]. RE also is a viable option in capturing the geometry of complicated design models. Partnered with AM, both technology enables various physical products to be built from a digital model with relatively high complexity in product geometries and shapes. As such, this project is executed to help Melaka History and Ethnography to generate both the digital and physical mock-up of the artifact. Thus, this paper discussed the dimensional accuracy issue of a 17th-century flintlock Dutch gun. Despite the benefits and advantages of both technologies, the dimensional accuracy of the printed object has become the main issue [3]. The main concern is the STL data quality obtained from both non-contact RE scanners, and the dimensional accuracy of the 3D printed mock-ups of the artifact fabricated using AM technology of binder jetting and laser sintering (LS) machine.

2. METHODOLOGY

Figure 1 shows the process flow of the project methodology and the experimental works of the research comprehensively.

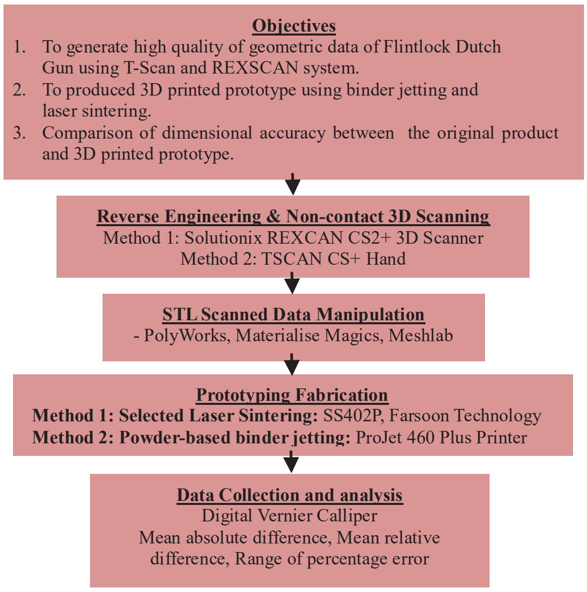

Figure 1 Project methodology process flow chart

Two non-contact 3D scanners were used: (i) Solutionix REXCAN and (ii) ZEISS T-Scan. The non-contact technique is best for faster scanning process, higher point cloud density, and intactness of scanned object's surface. The data acquired from the scanning process then were transferred to Standard Triangle Language (STL) file. Then post-processing and data manipulation of the point cloud was done using PolyWorks MS 2018, and Meshlab software. The final STL files then were verified using Materialise Magic.

The fabrication of the prototypes was done using Projet 460 Plus binder jetting and Farsoon LS machine. The prototypes were printed in XY and YZ directions of part orientation to achieve the optimum dimensional accuracy and surface finish. The prototypes went through a post-processing process before being measured. Table 1 summarises the characters of the printed prototypes.

Table 1 Characteristics of printed prototypes

Prototype	3D scanner	Printer type	Material
1	REXSCAN	Binder jetting	VisiJet PXL
2	REXSCAN	LS	50% recycled nylon, 50% raw nylon
3	T-Scan	LS	

The measurement of the dimensions was done using a digital Vernier caliper since the artifact is not considered as a precision object, and the scanning just generates the data of the outer surface. Eight interesting measurements were considered, these include the dimensions in X, Y, and Z directions, a diameter, and a special feature of interest. Each measurement of the artifact and printed prototypes was repeated 3 times. Results were analyzed and average values were compared against each other. Figure 2 below shows eight features being measured for dimensional accuracy.

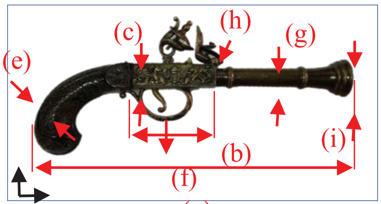

Figure 2 The measured features on the artifact in X, Y, Z directions

3. RESULTS AND DISCUSSION

3D printed parts may slightly deviate from the actual dimensions. The dimensional error was calculated as the absolute difference between the measured dimension obtained from the prototypes and the artifact [4]. Then, relative differences (%) were determined as the absolute difference divided by the dimension of the artifact by a value of 100 [4]. The mean absolute difference represented the deviation of the average dimension of the paired samples. However, the mean relative difference can be defined as the percentage of error. The range of percentage of dimensional error is determined to find out the final result. The lowest percentage of error represents the accuracy of the printed prototypes when compared to the artifact. The formula of mean absolute difference and mean relative difference are shown below respectively:

Mean absolute difference (mm):
The average dimension of the artifact value - average dimension of prototype value. (1)
Mean relative difference (%):
(Average dimension of the artifact - Average dimension of the printed prototype)/ (Average Dimension of the artifact) x 100%. (2)
Range of percentage of error:
Highest values (maximum) – lowest values (minimum). (3)

Table 2 shows the comparison of the mean absolute difference (mm), mean relative difference (%), and range of percentage of dimensional error between the original artifact and the printed prototypes.

Table 2 Comparison of value error between original artifact and 3D printed prototypes

Prototype	Mean absolute difference(mm)		Mean relative difference (%)		Range of error (%)
	Min	Max	Min	Max	
1	0.04	0.37	0.013	1.868	1.885
2	0	0.37	0	1.391	1.803
3	0.05	1.08	0.01	12.13	12.12

Based on Table 2, it shows that Prototype 3 has the highest mean relative difference of 12.13% at feature (d) in the Y-axis direction. On the other hand, Prototype 2 has the lowest minimum mean relative difference which is zero at feature (f) in the Z-axis direction. The results also show that Prototype 2 has the lowest percentage error at 1.803%. This result indicates that Prototype 2 has the most accurate dimensions compared to the other two prototypes. This result also proves that the Solutionix REXCAN 3D scanner able to produce high quality and a high degree of dimensional accuracy of scanned data with a low percentage of error. On the other hand, it also proves that the LS process can build an ultra-fine detail surface.

4. SUMMARY

The investigation proves that RE and AM is a reliable technology for various applications. The results revealed that the combination of Solutionix REXSCAN 3D scanner and LS machine produced a high dimensional accuracy, decent surface finishing, and fine detail 3D printed historical artifact, and also indicate that there is a small deviation of dimensional accuracy of 1.803% between the original Dutch gun and the 3D printed replica which is within an acceptable tolerance.

REFERENCES

[1] T. Segreto, A. Bottillo, R. Teti, L. M. Galantucci, F. Lavecchia, and M. B. Galantucci, "Non-contact Reverse Engineering Modeling for Additive Manufacturing of Down Scaled Cultural Artefacts," *Procedia CIRP*, vol. 62, pp. 481–486, 2017.

[2] O. Folorunso and F. Folorunso, "Preservation and Conservation of Yoruba Cultural Artifacts: The Place of Nigerian Libraries and Archives," *African Research Review*, vol. 6, no. 1, pp. 256–262, 2012.

[3] I. Baturynska, "Statistical analysis of dimensional accuracy in additive manufacturing considering STL model properties," *International Journal of Advanced Manufacturing Technology*, vol. 97, no. 5–8, pp. 2835–2849, 2018.

[4] D. N. Silva, M. Gerhardt de Oliveira, E. Meurer, M. I. Meurer, J. V. Lopes da Silva, and A. Santa-Bárbara, "Dimensional Error in Selective Laser Sintering and 3D-printing of Models for Craniomaxillary Anatomy Reconstruction," *Journal of Cranio-Maxillofacial Surgery*, vol. 36, no. 8, pp. 443–449, 2008.