Design Innovation for Replica Trophy Using Reverse Engineering and CNC Machining

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DECLARATION

This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree

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LIST OF ABBREVIATIONS

2D   - Two-dimension

3D   - Three-dimension

CNC   - Computer Numerical Control

CAD   - Computer-aided Design

CAM   - Computer-aided Manufacturing

CMM   - Coordinate Measuring Machine

CATIA   - Computer Aided Three-Dimensional Interactive Application

EDM   - Electrical Discharge Machine

NC   - Numerical Control

RE   - Reverse Engineering

LIST OF FIGURES

ABSTRAK

Trofi adalah sejenis objek hiasan yang diberi kepada pemenang dalam sesebuah pertandingan. Ia datang dalam pelbagai jenis dan bentuk yang berbeza. Ia bermula dari zaman kunoYunani di mana ia diberikan untuk pemenang dalam peperangan dan direka bentuk dengan butiran peperangan. Dalam cara tradisional, mereka membuat trofi ini dengan menggunakan tangan. Trofi dibuat daripada kayu mahupun batu. Menghasilkan trofi menggunakan tangan memerlukan masa yang lama. Dengan teknologi yang tersedia, teknik kejuruteraan terbalik diterapkan pada objek yang sedia ada kemudian diinovasi menjadi sesuatu yang baru. Teknik kejuruteraan terbalik adalah teknik yang paling popular yang digunakan untuk mencipta produk lain yang menyerupai objek sedia ada tanpa memerlukan dokumen asal atau pengukuran dari produk sebenar. Kemudian dengan menggunakan pengimbas 3D, ia boleh memodelkan objek fizikal untuk membuat 3D geometri pengiraan. Pengimbas 3D digunakan untuk mengimbas objek sebenar dan membuat satu yang lain menyerupai bentuk yang sama supaya mereka boleh diubahsuai atau dianalisa di dunia digital. Pengimbas 3D ini adalah antara cara terpantas,tepat, dan automatik untuk memperoleh data. Daripada itu, kita dapat memperoleh semua data yang diperlukan dan boleh memperbaiki rekabentuk sebenar untuk rekabentuk yang lebih baik. Objek ini boleh diubah suai dalam model CAD untuk membetulkan ketidaksempurnaan dan melakukan peningkatan dengan menggunakan perisian yang sesuai seperti perisian CATIA. Perisian CATIA boleh menyediakan model permukaan atau model pepejal yang lebih rumit, mengikut mana-mana hasil akhir yang diperlukan. Dengan menggunakan pemesinan CNC untuk menghasilkan produk, ia dapat mengurangkan masa yang diambil selain dapat menghasilkan kualiti permukaan yang lebih baik. Dalam projek ini, produk dipilih berdasarkan beberapa kriteria kemudiaan menjalani teknik kejuruteraan terbalik dan dihasilkan dengan menggunakan mesin CNC. Kemudian, parameter produk yang dihasilkan dengan menggunakan teknik kejuruteraan terbalik akan dibandingkan dengan rekabentuk produk sedia ada. yang sedia ada. Selain itu, dimensi dan saiz produk yang dimesin juga akan diuji. Bagi hasil perbandingan parameter antara produk yang dihasilkan, dengan rekabentuk produk sedia ada, ia mempunyai 5 jarak yang telah di daftarkan untuk diukur. Peratusan perbandingan jarak antara Jarak 1, Jarak 2, Jarak 3, Jarak 4 daan Jarak 5 masing-masing adalah 4.20%, 5.63%, 8.95%. 0.17% and 0.09%.

ABSTRACT

Trophy is an object that give for a winner in a competition. It comes in many types and in different shape. It is started from ancient Greece where it given for a winner in a war and be design with the details of the war. In traditional way, they create this trophy by using hand. They create the trophy on the wood and even create it on the stone. Making a trophy by using hand takes a lot of time to produce it. With the technology that available in this world, reverse engineering technique is applied to the existing objects then innovate it become something new. Reverse engineering technique is most popular technique that use to create another products that similar to the existing object without having any original document or measurement from the real products. Then by using a 3D scanner it can digitalizing physical objects to create 3D computational geometry. 3D scanners used to capture real object and makes another one in the same shape so that they can be remodeled or analyzed in the digital world. This 3D scanner is the fastest, most accurate, and automated way to acquire. From that can get all the data needed and can improve the actual design to a better design. The object can be modified in the CAD model to correct imperfections and do the improvement by using the suitable software such as CATIA software. CATIA software can provide a surface model or the more complex solid model, whichever results are needed for the application. By using CNC machining to produce the products it can reduce the time taken besides can produce a better surface quality. In this project, the products are choose based on some criteria then it will also undergo with the technique of reverse engineering and producing by using CNC machine. . Then, the parameters of the produced product by using reverse engineering technique will be compared with the design of existing product. Besides, the dimension and size of machining part also be tested. For the parameters comparison result between the outcome product and design of existing product, it contains 5 distance that has been registered to be measure. The percentage different for Distance 1, Distance 2, and Distance 3, Distance 4 and Distance 5 are 4.20%, 5.63%, 8.95%. 0.17% and 0.09% respectively.

CHAPTER 1

INTRODUCTION

1.1 Background

Trophy is an object look such a cup or sculpture that is given as an awards for a winner that are given primarily for sport competition, academic work or events. It also something that can keep or proudly displayed in homes, schools or others place. Trophies design are include of the figure, flora and fauna, sport equipment, or others objects that associated with the contest or the events in which the winner has succeed. All the trophies design will have extraordinary meaning and have a tangible evidence of prowess for the recipients.

Nowadays, trophy is getting high demands as it is still relevant to be given as an award in any events besides certificate. Many trophies are made of molded plastic colored to resemble with gold, silver or brass and are manufactured at a factory before assembled by sellers. The price range are from inexpensive to almost priceless that depends on design and material used. It can be unique and interesting trophies based on the design that must be relevant with the events.

"Sanggar Sanjung" has been choosing as a theme for this project because of it is a very special event for Universiti Sains Malaysia. It is the annual event for the University and this event is a celebration the contributions of the staff in some aspects for their efforts and achievements besides hard work and committed in careers. In this project as the designing and innovation of the replica trophy, a new techniques is used which is to produce a replica trophy of "Sanggar Sanjung" by using the method of reverse engineering and producing it with the CNC Machine.

Reverse Engineering is used to summarize the process of reconstructing an already existing object [1]. In reverse engineering, the design engineer starts with the final product and works through the design process in the opposite direction to arrive at the product design specification. During the process, vital information about the design concept and manufacturing methods is discovered. In this project, the two or more types of replica trophy will be scan by using reverse engineering techniques before produce the new product design.

This techniques that is proposed basically as a method to produce a new replica trophy of "Sanggar Sanjung" event. This trophy will come out with a design that are relevant and suitable with the concepts. The process need to identify the products first before come out with the real products because in reverse engineering it works from back to the front. In the other hand, it might be a first replica trophy in this event because the previous years all the recipients will get a certificate of appreciation. It will be produce by using material which is aluminum 6061 and produce by using CNC Machine. In conclusion, this project will produce a new replica trophy of "Sanggar Sanjung" by identify a suitable products before produce it by using reverse engineering and also by CNC Machine.

1.2 History of Trophies

Basically, trophy word is derived from Greek "tropaion", and that comes from the verb "trope" that means "to rout". In ancient Greece, trophies are given for winner in a war, and are created on the battlefield where the enemy had been defeated. Each trophies will include arms and standards, then will hang upon a tree or large stake to resemble the figure of a warrior. The tropes are design with the details of the war and dedicated to a god and then it must be left to decay naturally.

The Romans continued the custom but preferred to construct trophies in Rome, with columns or triumphal arches serving the purpose in imperial times. They also wanted to keep the trophies closer to home. The Romans had special trophies that constructed in Rome, there are remains of huge stone memorials that are originally crowned with sculpted stone trophies. In Figure 1.1 there are trophy that built by Augustus at La Turbie (near Nice, Fr.).
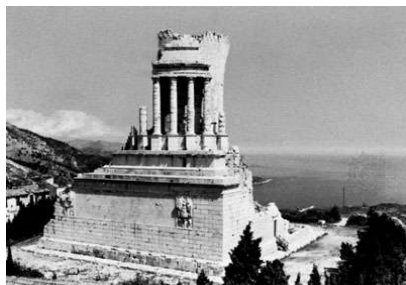
Figure 1.1 Trophy of Augustus at La Turbie, Fr. 7–6 BC

1.2.1　　　Sport Trophies

Sport trophies are defined as a symbol or token of victory in a competition. There are generally symbolized through form of miniature statue or figure and most typically colored gold or made from gold depends on the events. From football to hockey, and all the sports gives the winners with such trophies. A sportsmen and athletes appreciation the trophies more than other prize because for them a trophy symbolized victory and it make them proud to receive it. The trophies also turn out all their challenges, their efforts during practice and training which led to their achievements.

Sports like football give trophies to the best performing teams. Some of the trophies are highly valued such as FIFA World Cup competition. Probably the world's most prestigious and expensive trophy is the FIFA World Cup Trophy because it made from solid gold (e.g. Figure 1.2). Not all football trophies are crafty but still the trophies are given at all level in this sports as the only form of appreciation the participants get for their dedication throughout the season.

Figure 1.2 Trophy of FIFA World Cup

Furthermore, no matter how different the trophies are or how the design it they would be, all of them whether given in rugby (e.g. Figure 1.3), football or crickets games, they bring the same values and hold the same importance for the participants. So, such trophies are not just metal or wood, but the symbol of victory itself and all the hard work is pay off by achieving the trophies.

Figure 1.3 Rugby World Cup Trophy

1.3 Trophy Design

Basically, the traditional tools that being used before to draw such as pens, drafting board, T-square, French curves, templates and perspective machines, rulers, compass. Drawing board or drafting board is a tool which commonly attach with the T-square. Nowadays, these tools to do drawing is rarely being used. It is because due to the time taken to draw by using those tools is longer and lead to longer period to finish one drawing. Other than that, it is requires a lot of skill to draw by using a traditional tools. For example to create an arc segments need a lot of lines and circle. Moreover, it will leave a lot of unnecessary reference lines and it will cause the drawing looks bad.

Therefore, in this era of technology, some of the company created a software for design such as SolidWorks, CATIA, AutoCAD, and etc. that can help the designer producing a drawing in a short time. Furthermore, this software design also does not required a lot of skill and can be learn in short time and can learn at any By this help of those software, the designer could also doing some simulation based on the product that they design. This can make the product looks more interesting and can make a correction in easy way without leave any unnecessary reference lines on the papers.

1.3.1   Trophies Innovation

Basically innovation is define as new idea or method. It is also can be defined as something that is original and more effective. Besides, innovation has become an important driving force for the economic growth in modern technology nowadays. It is one of the strategies which can increase the income for some company besides can produce more unique and interesting product. Innovation also is something that doing an improvement of the existing product or else producing a new product that is not available in the market which can give benefits to the society. Mostly Research and Development Department is always involved in this project of innovation

Example of the innovation that the human being has made from the past year such as automobiles, mobile phones, and etc. Past a few years, television only created in small size and does not have any color on the screen. But now, as the era of technology, television comes out with various type and brand such as Samsung, Panasonic, LG, Sony, Toshiba, Sharp and etc. which helps a lot in get information and many more functions.

1.4 "Sanggar Sanjung"

"Sanggar Sanjung" has been choosing as a theme for this project because of it is a very special event for Universiti Sains Malaysia. "Sanggar Sanjung" are means the "hall of fame" [2]. This is an annual event for the University. This event is to celebrate the outstanding contributions of the staff in some aspects and honors for their efforts and achievements. Besides, this event for celebrating of successful collector and personal satisfaction that honors the creative and innovative. The reward are given for their hard works, dedication and their commitment to excellence. This awards are involve all staff from each campus which are main campus, engineering campus and health campus.

1.4.1   History of Sanggar Sanjung

The Sanggar Sanjung or Hall of Fame event are began from 2001 is a special event to celebrate outstanding contributions of USM staff in research, personality, creativity publications, quality, and teaching categories and who had received awards for their efforts and achievements.

There are different logos have been created for this Sanggar Sanjung's events every year, since its inception. However, in 2013 the Sanggar Sanjung Award Committee decided to use the logo (Figure 1.4) as the official logo of this event. The Sanggar Sanjung Award logo represents the strength and glories in the field of academic, research, services and networking, by staff of Universiti Sains Malaysia's community. It resonates the university's principles and activities.

Figure 1.4 Sanggar Sanjung Award Logo

1.5 Problem Statement

By using Reverse Engineering technique the innovation of a new design for replica trophy from combination of product need to be redesign and produce it by using CNC Machining based on "Sanggar Sanjung" as a theme. However, there are no original drawings and original measurement data are available then we need to use Reverse Engineering to evaluate all the data to improve the product design and produce the new replica trophy. Technology such as reverse engineering and CNC machine could be the suitable method than can be applied in producing this replica trophy for the event.

1.6 Objectives

This project have objectives that need to achieve based on designing and also the fabrication. The objectives of this project are:

- To identify a suitable trophy design that related with a theme "Sanggar Sanjung"
- To create a new design of replica trophy from combination of product by using Reverse Engineering technique
- To produce a real replica trophy by using CNC machining.

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1.7 Scope of the Project

In this project, designing innovation of replica trophy is done by combining two different types of product becomes one replica trophy. First need to find all the requirements before produce or decide to combine the products become a new design. The products that have been choose should be related and suitable with the theme of 'Sanggar Sanjung' event which is it celebrates the outstanding contributions of the staff in several aspects and honors them for their efforts and achievements.

The selected product will be scan by using 3D scanner before proceed with the innovation of new design by using the software that is provided which are SolidWorks and CATIA V5. The 3D scanner that is involved in this project is 3D Scanner Next Engine.

Besides, this project need to be fabricate by using the CNC machine besides the material that is have been used to produce is by using aluminum 6061. The CNC machine that is involved was CNC 5-axis milling machine DMU 40 Mono Block Deckel Maho. Some discussion were made to clarify the different in result that is obtain from the process that is done and the technique that is being used in this project and also to be tested based on the dimension and the size of the product with the existing product and design because the different result will get in the end of process.

1.8 Outline of Thesis

This thesis consist of 5 chapter which are:

Chapter 1

- Including project background, definition of design innovation for replica trophy by using reverse engineering and CNC machine, problem statement, project objectives, scope of project and thesis organization.

Chapter 2

- This chapter include all the review of the other literatures that had done the research which is related with this project.

Chapter 3

- This chapter will explain about the methodology of the project. The content include the flow chart of project, the scanning and editing process, material selection and machining process.

Chapter 4

- This chapter will include the result and discussion of the project. The data that acquired from this project will be analyzed and will be compared.

Chapter 5

- The last chapter is about the conclusion and also the future work will be included in this chapter.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

Until recently, the researcher have shown their interest on reverse engineering by producing many types of products. For reverse engineering, 3D scanner is most of important part to scan the product before proceed to another step. There have many types of 3D scanner. Other than that, nowadays also people start to produce the product by using CNC machine. In this chapter will explain about the reverse engineering, 3D scanner and CNC machine that involve in this project.

2.2 Reverse Engineering

Reverse engineering (RE) method are representing important part in prototype creation [3]. One of the option the used of reverse engineering method is servicing which is process of changing and repairing in the shortest time. In the other hand, part changing could taking a longer time when the spare part is not available. Thus, this is why the usage of reverse engineering is important since it can reduce the repair time to minimum.

Besides, reverse engineering is one of the unlocked achievement in reaching the modern technology. Reverse engineering is a wide field. From its name "reverse", we can know that the cycle or a process is moving in opposite way from the conventional way. In CAD technology, reverse engineering is a process to obtain data or information from the existing product without aid of technical drawing, documentation or raw data by scanning or digitizing the existing product [4].

In achieving industry 4.0 [5] this approach plays an important role. It makes modification and improvement process easier and beneficial. This is because there are some circumstances that the conventional way is no longer applicable. In manufacturing industry, competing each other is normal especially in achieving the improvise technology. That is why we can see that nowadays reverse engineering is widely used in several of

application such as manufacturing, industrial design and even in jewellery design and reproduction.

Performing the reverse engineering, it involves several stages. It starting with collecting the data for the product [6] such as shape, structure, material, surface quality and dimension. This stage can be done by scanning process. In this phase, it will involve contact scanner and non-contact scanners. For contact scanners, the CMM contact probe [7] is usually used. However this method is not suitable when working with large size of part or product. For non-contact scanners, it involves 3 dimensional scanner that used either laser, optics or charge-coupled device. This method is more advanced compared to previous method.

The outcome from the scanning process is a cloud of data points [8]. This point cloud later will be used in reconstructing the technical drawing in CAD. In point processing phase, reducing or adding point cloud data can be done. Therefore, this is how it will be used in improvement or doing modification to the existing product. Reverse engineering is very beneficial in investigating the principle of technologies of a device. It is not limited in CAD only. It can be widely used in engineering field in order to improve the current technologies.

2.3 3D Scanner

The study in semi-automatic low cost 3D laser scanning systems for reverse engineering is carried out to emphasize on the development, implement, and testing of a semi-automated low cost motorized 3D slit laser scanning system. The DAVID Laser Scanner Vision System GmbH's [9] is used as the foundation of the scanner. The CNC milling machine is installed with motorized motor and the Mach3 CNC software is used as the controlling system. The experiment by combining and personalizing the different software. They also wrote a specific program and compiled it for processing and established the communication between the scanning software and the control software of the CNC machine by throwing two double virtual communication ports. The result showed that the laser scanning system can be used by implementing simple or retrofitted hardware for motorized movement and interfacing different low cost or open source software modules [9]. However, the study has room for an improvement such the optimization of

the algorithms, monitoring the parameters of the system, improving the communication with Mach3, and increase the measurement accuracy with using different optics, sensors, and geometrical setup.

The study of reverse engineering of parts with optical scanning and additive manufacturing is carried out with the purposes of introducing the reverse engineering procedure, what can be done to the procedure, and remanufacture car's volume button [10]. By using 3D scanning technology as the medium to determine the point cloud of the car's volume button due to its free formed surfaces. 3D CAD model [11] will be developed with the aid of the point cloud and proceed to manufacture the volume button. The result showed that the reverse engineering is useful method for manufacturing the already existing pieces [12]. Based on observation, the working principle of the 3D scanner and its implementation in reverse engineering field. The usage of different software enable the authors to repair the mesh, orientate the mesh, and define the position of the mesh. The solid design of the complex form volume button is created by using SolidWorks. The selective laser sintering machine enable to manufacture the pieces easier and cheap.

In cultural heritage field reverse engineering method has a relevant role and 3D digital model of the artefacts open a new path to in this field. Emphasizes two different non-contact reverse engineering scanning system for the 3D data acquisition of the cultural heritage artefact. The additive manufacturing technologies are being applied to reconstruct a down scale copy of the artefact. As the result, two non-contact reverse engineering [13] systems are utilized for the reverse engineering of the cultural heritage artefact consisting in a II century monolithic marble column of Roman making; a portable measuring arm (PMA) with laser scanner and a system based on digital close range photogrammetry (DCRP). The two digital models are obtained from each reverse engineering systems and they are comparatively evaluated in terms of point clouds and polygon meshes. The evaluation is based on the colored maps that defined the minimum and maximum distance between the two results.

Besides, the comparison between 3D model obtained by videogrammetry [14] and 3D model through the scanner laser. Scanner laser is easy handling and intensive data provided. It also has requires multiple data captures, subsequent filtering and a complex

data processing [14], but its accuracy dependent on the material. For the videogrammetry is can generate high number of images in a shorter time and not too depends on type of material. Besides time needed to complete each process is lower than use laser scanner. The process is automatic complete not required post-processing or filtering work. The videogrammetry also enables real 3D object visualization.

2.4 CNC Machine

Computer Numerical Control Machine or CNC Machine is fully automatic machine and has its own programmed. By using this machine, people can fabricate a product at easiest way and can reduce time [15]. CNC machine consist of three axes which are X-axis, Y-axis and Z-axis and even have 5-axes which add with A-axis and B-axis. Commonly the 5-axes could produce part that has a complex shape and angle with short period of time. The consideration of the axis of the cutting tool must stand in normal towards the surface of material. Solution that can be applied during process of the 3D surfaces is the decomposition of a solid into successive sections. To produce the replica trophy it is suitable to use 5-axis CNC machine as this machine could cut a very complex shape, have a better control of tool positioning, efficient utilization of tools, reduction of machining time, and shorter process planning phase. By using this machine also can produce a big size of product with limited number of tool positioning [15].

There are a lot of types of CNC machine that available in this world. For example router, plasma cutter, milling machine, lathe, CNC laser cutter and EDM Wire cut [16]. The programmed or code that is used to generate a movement to the CNC is called as a G-code which this code

Error due to the machining dimension can cause the assembly of machine part and also the performance variability. The accuracy and repeatability of machine tools are important in order to achieve and maintaining a quality part. Some example of the error that can affect the quality of the part such as tool wear and deflection [17], the clamping error and work piece location and also work piece deflection. Others error in CNC machine tools that can affect the accuracy and repeatability [18] of part manufacturing including force and stress, geometrical deviations of machine tool structure, thermal variations, and cutting force induced errors.

CHAPTER 3

METHODOLOGY

3.1 Overview

In this chapter, the process of producing the replica trophy are shown step-by-step until the real product is produce. The input of this project is about producing the innovation of replica trophy from combination of products based on theme of 'Sanggar Sanjung' event. The reverse engineering technique is involved in this project which means the selected product are choose then will be scan to duplicate of an existing part by capturing the component's physical dimensions, features, and material properties. This project input is start by scan the product with 3D Scanner Next Engine then will be producing a real product by using the 5 axis CNC machining.

3.2 Overall Process Flow Chart

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             ╱   REPLICA TROPHY    ╱
            ╱────────────────────╱
                          ▼
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            │  Search about the theme  │
            │    given 'Sanggar        │
            │  Sanjung' and the concept│
            └────────────┬─────────────┘
                          ▼
            ┌──────────────────────────┐
            │    Find the suitable     │◄──────┐
            │        products          │       │
            └────────────┬─────────────┘       │
                          ▼                     │  No
                    ◇───────────◇               │
                   ◇  Finalize   ◇──────────────┘
                   ◇ the products◇
                    ◇───────────◇
                          │ Yes
                          ▼
            ┌──────────────────────────┐
            │    Scan the products     │
            └────────────┬─────────────┘
                          ▼
            ┌──────────────────────────┐
            │   Edit the scan objects  │
            └────────────┬─────────────┘
                          ▼
            ┌──────────────────────────┐
            │ Innovate the design by   │
            │ combine the both of scan │
            │ products become a new    │
            │ design of replica trophy │
            │ using Solid Works or     │
            │ CATIA V5                 │
            └────────────┬─────────────┘
                          ▼
            ┌──────────────────────────┐
            │ Set-up the aluminum 6061 │◄──────┐
            │   into the 5 axis CNC    │       │
            │        Machine           │       │
            └────────────┬─────────────┘       │
                          ▼                     │  No
            ┌──────────────────────────┐       │
            │ CNC machine will cut the │       │
            │ aluminum according to    │       │
            │ design                   │       │
            └────────────┬─────────────┘       │
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                          │ Yes
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